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Impacts of Technology on U.S. Cropland and Rangeland Productivity

Volume II—Background Papers

Part F

Paper No.

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28. Credit and Credit Institutions as Factors Affecting the Long-Term Productivity of U.S. Rangelands and Croplands
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Preface

This volume contains papers written for OTA to assist in preparation of the report *Impacts of Technology on U.S. Cropland and Rangeland Productivity.* OTA does not endorse these papers. In several instances, the OTA report reaches somewhat different conclusions because of additional information which was obtained later. These papers, however, may prove valuable for readers needing more detailed or specific information than could be accommodated in the final assessment report, and are being made available for such purposes.

Background Paper No. 27

THE ADOPTION AND DIFFUSION OF TECHNOLOGICAL INNOVATIONS IN U.S. AGRICULTURE

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Office of Technology Assessment
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This background paper was prepared for the assessment "Impacts of Technology on U.S. Cropland and Rangeland Productivity." The views expressed are those of the author(s) and not necessarily those of OTA.

INTRODUCTION

The purpose of this paper is to describe the diffusion process through which agricultural innovations diffuse in the United States. We place special emphasis upon technological innovations that act to maintain, degrade, or enhance the long-term productivity of farm land.

BACKGROUND ON TECHNOLOGICAL INNOVATIONS

In recent years, it has increasingly been recognized that certain technological innovations may have indirect, delayed and dangerous consequences. Among the many examples are:

* The danger of nuclear power plant accidents, highlighted in 1979 by the accident at Three Mile Island.
* Cancer-causing consequences of cigarette smoking, asbestos, and diethylstibestrol (once used as a morning-after birth control method, and for fattening beef cattle).
* Life-threatening results of certain human and animal drugs, pesticides, and weedicides. An example is 2,4-D weed spray (whose diffusion the present author had investigated in his Ph.D. dissertation in Iowa in the mid-1950's, then in Ohio, and, in the mid-1960's, among peasant farmers in Colombia), whose use by farmers was discouraged by the U.S.D.A. in the 1970's.
* The recall of millions of automobiles, ordered by the U.S. government, because of safety hazards in the autos' design and construction.

Early warnings about the dangerous side-effects of technological innovations were voiced by such critics as Rachel Carson in her 1962 book Silent Spring (pointing out the lethal effects of chemical residues in farm products) and Ralph Nader's (1964) Unsafe at Any Speed (a book that criticized General Motors'

Corvair, leading to its recall). At first, such outcries were treated with scorn by scientists and others in positions of authority. For example, organic gardeners and farmers in the U.S. were regarded by agricultural experts as crackpots because they refused to use chemical fertilizers, pesticides, or weed sprays. However, by 1980 an estimated 1 percent of U.S. farmers, about 25,000 to 35,000, considered themselves organic farmers.

Eventually agricultural scientists were forced to conduct investigations to determine the advantages and disadvantages of organic farming compared to conventional farming (this U.S.D.A. investigation was instigated by U.S. Secretary of Agriculture Bob Bergland because one of his neighboring farmers back home in Minnesota had switched to farming his 1,500 acres organically). The U.S.D.A. gathered data on organic farms in the U.S., Europe and Japan, and concluded that there were no differences in crop yields under comparable conditions. And the cost of inputs were often less, due to the increasing prices of agricultural chemicals caused by energy prices.

So in 1980, the U.S.D.A. and state agricultural extension services began (1) research to find improved methods of organic farming (like new crop varieties that are not geared to chemical fertilizers and pesticides), and (2) diffusion efforts to encourage the adoption of the organic farming innovations (and to discourage the use of such innovations as agricultural chemicals that had been previously recommended).

Problems of environmental contamination are becoming increasingly serious in U.S. agriculture. For example, in the present author's home community in Western Iowa, human and animal water supplies are contaminated with nitrates which kill or deform the young. In many sections of rural Iowa today, ground water is nitrate-contaminated to a depth of 300 feet or more. Farmers must dig increasingly-deeper wells (at a cost of $10-15 per foot for drilling plus about

$3,000 for pipes and other equipment) or else avail themselves of rural water systems (many of which are financed through loans from the Farmers' Home Administration) , which bring in water from as far away as 50 miles or more (although at a cost per gallon that usually precludes using such water for animals).

Discouragement with certain technological innovations, such as nuclear power, agricultural chemicals, etc. led to the rising importance of such watchdog regulatory agencies as the Pure Food and Drug Administration, the Environmental Protection Agency (EPA), and the Office of Safety and Health Administration (OSHA). These powerful Federal agencies mainly act to discourage the diffusion of certain technological innovations, and to encourage the discontinuance of such innovations that are found to be unsafe. Other government and government-related organizations like the Office of Technology Assessment (of the U.S. Congress) and the National Academy of Sciences act to evaluate the risks associated with certain technological innovations.

One of the particular problems facing U.S. farmers is the forced discontinuance of agricultural practices as a result of the enforcement of environmental and/or health quality legislation (Mason and Halter, 1980). For example:

- DDT as an insecticide has been banned.
- Diethylstibestrol (DES) in animal feed has been suspended.
- Field burning in many areas of the U.S. is strictly controlled by air pollution authorities.

Certainly the times have changed during the 1970's in the U.S., from generally enthusiastic public opinion about technological innovations as solutions to social problems, toward an era of widespread doubt about the omnipotence of science and technology. Events like the Santa Barbara oil spill, Three Mile Island, the SST airplane, and the Dalkon shield mark this change in public perceptions of technological innovations, and of science itself. We have belatedly come to realize that our high-technology society is increasingly complex, interdependent, and dangerous.

This basic realization represents an entirely different context for work on the diffusion on innovations than existed in a previous era. No longer should diffusion researchers unquestioningly assume that the technological innovations of study are beneficial for all the intended adopters. In fact, it may be important and useful to investigate the discontinuance of such innovations after they have been found to be dangerous by technical experts. Such issues need to be investigated as what happens to the perceived credibility of a diffusion agency (like the U.S.D.A., for example) when they suddenly reverse their position from promoting agricultural chemicals to encouraging organic farming.

Technological innovations that provide at least partial solutions to certain of the environmental contamination problems discovered previously are also being found, and are diffusing among U.S. farmers.

1. No-tillage agriculture (or minimum-tillage agriculture, in which only a disc or a chisel-plow is utilized to prepare the ground), leading to less erosion and lower fuel costs.
2. Tilling up and down hillsides to carry off the accumulated water in contoured terraces, and thus diminishing the problem of the run-off water eroding grassed spillways.
3. Close monitoring of chemical spraying, so as to minimize any unnecessary spraying.
4. Organic farming.

Now we turn to a discussion of past research on the diffusion of innovations.

THE DIFFUSION OF INNOVATIONS

Research on the diffusion of innovations today represents one of the largest single areas of behavior science research, and a type of investigation carried out in a wide variety of nations. But during the 1970's, a number of criticisms have been directed at diffusion research. These critical analyses represent a healthy intellectual exercise, and I believe they have led to important rethinking about diffusion, to a reorientation of certain diffusion researches, and to new types of diffusion programs that seek to remedy some of the criticisms of the past. If diffusion research is to maintain the healthy viability that it demonstrated over the past 40 years, it must change appropriately to suit the times. Research by diffusion scholars during the 1970's has led to important modifications in the "classical model of diffusion"; the most important of these modifications shall be detailed in this chapter.

Historical Background

Research on the diffusion of innovations dates back to the 1930's, but the real growth spurt of diffusion studies began in the 1950's and a continued expansion in the number of diffusion publications continues to the present. Few fields of social science research have received so much attention by scholars in so many disciplines and in so many nations for so many years. A dominant intellectual paradigm (the so-called "classical diffusion model") ruled these studies, giving a consistent coherence to the field but also somewhat limiting the scope and method of inquiry. To a certain extent, many diffusion studies looked a great deal alike.

The Popularity of Diffusion Research

"Innovation has emerged over the last decade as possibly the most fashion-able of social science areas" (Downs and Mohr, 1976). Various behavioral science disciplines are involved in the study of innovation, including in recent years scholars of organizational behavior. "This popularity is not surprising. The investigations by innovation research of the salient behavior of individuals, organizations, and political parties can have significant social consequences. [These studies] imbue even the most obscure piece of research with generalizability that has become rare as social science becomes increasingly specialized" (Downs and Mohr, 1976).

What is the appeal of diffusion research to scholars and to sponsors of such research? Why is there so much diffusion literature being produced today? Why has there been only modest impact at best on management practice and policymaking?

1. The diffusion model is a conceptual paradigm with relevance for many disciplines. The multidisciplinary nature of diffusion research cuts across various scientific fields; a diffusion approach provides a common conceptual ground bridging these divergent disciplines and methodologies. There are few disciplinary limits on who studies innovation. Most social scientists are interested in social change; diffusion research offers a handy avenue to such understandings (or so it seems). Economists are centrally interested in growth; innovation is one means to get it, and its patterns of diffusion may provide an important indicator of development. Organization scholars are concerned with processes and patterns of change in and between institutions, and in how their relation to structure is altered over time. Social psychologists try to understand the sources and causes of behavior change. The diffusion approach offers something of value to each of these disciplines.

2. The apparent pragmatic appeal of diffusion researcn is high. A

diffusion approach seems to promise to provide solutions to individuals and/or organizations (a) which have invested in research on some topic and seek to get it utilized, and/or (b) desire to use the research results to solve a particular social problem (for example, urban traffic problems). This promise has attracted policy and management researchers even though its fulfillment has yet to be fully proven in the arena of practice.

3. The focus of diffusion research on tracing the speed of an innovation (through a system in time and/or in space) has the unique quality of giving "life" to a behavioral change process.

4. The diffusion paradigm allows scholars to repackage their empirical findings in the form of higher-level generalizations. Such an orderly procedure in the growth of the diffusion research field has allowed it to progress in the direction of a gradual accumulation of empirical evidence.

5. The methodology implied by the classical diffusion model is clearcut and relatively facile. The data are easy to gather; the methods of data-analysis are well laid out. As Rogers (1962) stated, diffusion scholars have often dug where the ground was softest; they focused especially, and almost predominantly, on characteristics related to innovativeness through cross-sectional analysis of survey data. Although the methodological straightforwardness of diffusion studies encouraged many such investigations to be conducted, it also may have restricted theoretic advance.

The "Classical Model" of Diffusion

Communication has in the past often been defined as the process by which an idea or innovation is transferred.* Thus, the purpose of communication is to bring about certain desired effects on the part of the receiver; alteration of the receiver's knowledge of some idea, a change in attitude toward the idea, or a change in his overt behavior. Thus, a concern with communication implies an interest in behavioral change, as the purpose of most human communication is change. Although communication and social change are not synonymous, communication is an important element throughout the social change process. Essentially, the concept of social change includes, in addition to the communication process, the societal and individual consequences that result from the adoption or rejection of an innovation.

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* This definition implies essentially a linear model of one-way communication acts, as compared to a convergence model of the communication process through which information is shared between two or more individuals as they move toward greater convergence or divergence in their view of some event (Rogers and Kincaid, 1980).

Diffusion is a special type of communication. Diffusion is the process by which innovations spread to the members of a social system over time. Diffusion studies are concerned with messages that are new ideas, whereas communication studies encompass all types of messages. As the messages are new in the case of diffusion, a degree of risk and uncertainty for the receiver is present, leading to somewhat different behavior on his/her part in the case of innovations than if he/she were receiving messages about routine ideas. The "classical model" of the diffusion of innovation has the following main elements: (1) the innovation, defined as an idea perceived as new by an individual, (2) which is communicated through certain channels, (3) over time, (4) among members of a social system.

Studies of the diffusion of innovations increased from about 100 publications in 1952 to over 3,000 in 1980. Of these 3,000 publications, about two-thirds are empirical research studies. The early 1960's mark the beginning of a sharp take-off in the number of diffusion studies in developing countries. During a 20-year period, the number of empirical diffusion researches conducted in developing nations increased from 54 in 1960 to over 1,000 in 1980. The diffusion of innovations model has had a very influential role in development activities in developing countries. The sharp growth of diffusion studies in developing countries after 1960 was due to the fact that technology was assumed to be at the heart of development, and innovativeness was thought to be one of the best single indicators of the multi-faceted dimension called modernization (Rogers, 1976). So micro-level investigations of the diffusion of technological innovations (e.g., in agriculture, health, family planning, etc.) among villagers were of direct relevance to development planners and other government officials in developing countries.

Preventive and Incremental Innovations

A preventive innovation is a new idea, x, that is adopted "now" in order to avoid the possible loss of a desired value, y, in the future. Thus, it minimizes losses. Examples are contraceptives, crop insurance, seat belts, fire alarms, etc. Most of the innovations studied in past diffusion research are incremental innovations. An incremental innovation is a new idea, x, that is adopted "now" in order to gain a possible increase in a desired value, y, in the future (Koontz, 1976). Examples are a new seed variety, a new clothing fashion, chemical fertilizer, etc. We know very little about preventive innovation-decisions, except perhaps that their rate of adoption is usually slower than for incremental innovations. The motivation to adopt a preventive innovation is often a cue-to-action, an event at a point in time that crystallizes an attitude into overt behavior. For instance, a cue-to-action to adopt family planning is often provided by an unwanted pregnancy, or by a pregnancy scare.

DECENTRALIZED DIFFUSION: AN ALTERNATIVE MODEL

Here we propose that in addition to the centralized diffusion model that has received major attention in the past, an alternative model of decentralized diffusion also exists and deserves to be described and investigated.

Centralized Diffusion Systems

In 1971, Professor Donald Schon of MIT wrote that "theories of diffusion have characteristically lagged behind the reality of emerging systems." Schon particularly singled out for criticism the classical diffusion theory, which he termed a "center-periphery model." This model, Schon (1971, p. 81) said, rests on three basic elements:

1. "The innovation to be diffused exists fully realized in its essentials, prior to its diffusion."

2. "Diffusion is the movement of an innovation from a center out to its ultimate users."

3. "Directed diffusion is a centrally-managed process of dissemination, training, and provision of resources and incentives."

As Schon (1971, p. 94) pointed out, this traditional type of centralized and vertical diffusion model not only prevails in theoretical writings but has become the "dominant normative model for diffusion." The best-known example of a center-periphery model of diffusion is the United States Department of Agriculture's (USDA) Federal Extension Service, which coordinates with the 50 state agricultural extension services. This program (with an annual budget of over $350 million per year) represents the largest public investment in a diffusion system in the U.S., and in the world (Rogers and others, 1977).

Extension services in their very early days in the United States (and in Japan, the Netherlands, etc.) identified, and then disseminated, the agricultural practices followed by the most successful farmers. In later years, a superstructure of agricultural research was connected to agricultural extension services as a source of agricultural innovations. And most extension workers tended to forget that innovations could come from farmers' experience, as well as from formal research and development.

Agricultural innovations stem from R&D activities by the USDA and by state agricultural experiment stations. The agricultural extension services operate in close collaboration with these public research organizations through state extension specialists, who are stationed in state agricultural universities. The specialists' responsibility is to convey agricultural innovations to county extension agents, who in turn diffuse these technological innovations to farm people. Thus, the agricultural extension services represent an extremely centralized diffusion system. Not only has this diffusion model been widely copied in the form of agricultural extension services in many developing nations, but it has also served as a basis for the design of several other U.S. Federal diffusion systems in recent years in such varied fields as vocational rehabilitation, mass transportation, energy conservation, and education (Rogers and others, 1977).

Schon's (1971) main criticism of this centralized diffusion model is that it may apply to certain classes of innovations "lying near the periphery," but that it fails to capture the complexity of innovations which evolve as they diffuse,* and that originate from numerous sources (not just the center). Moreover, as Schon sees it, the diffusion process does not consist primarily of centrally-managed information dissemination, but it should be shaped by user demands and problems that are met by innovations coming from other users.

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* This is "re-invention," a concept defined previously as "the degree to which an innovation is changed by the adopter in the process of adoption and implementation after its original development."

Schon's work serves as an admirable starting point from which to examine an alternative model of diffusion, based on the concept of decentralized, horizontal diffusion of innovations among adopting units. Decentralized, horizontal diffusion systems depend mainly on peer networks for transferring technological innovations among local-level units.

Here, we briefly describe how such networks operate in the Peoples' Republic of China and in the U.S., and then we suggest several propositions about how decentralized diffusion systems differ from the more conventional centralized diffusion systems.

Decentralized Diffusion in China

Diffusion in China is characterized by the use of exemplary units (production brigades, communes, or counties) as role models for the rest of the nation, and by "on-the-spot conferences" through which innovations originated by these model units are diffused to other adopting units throughout the nation. The innovation process, at least in the recent past,* was often started by broad policy directives issued from the "center"--that is, by Chairman Mao himself (until his death). These directives were distilled from the ideas of the masses, rather than coming from educated experts. Mao (1954) wrote that one should "take the ideas of the masses (about their needs and possible solutions) and concentrate them (through study, into more systematic innovations); then go to the masses and explain these ideas until the masses embrace them as their own, carry them out and persist in this on their own; then test the correctness of these ideas in action." This statement, in short, reflects a decentralized type of diffusion.

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* The decentralized diffusion experiences described here existed in China at least until 1978, when the author visited the Peoples' Republic of China. Since then, the "Coca Cola-ization" of China may have changed the prior emphasis upon decentralized diffusion, but the extent of such change is not yet clearly understood.

The local unit which perhaps best illustrates how a nationally-recognized model serves as a dissemination point in a decentralized diffusion system is the famous Tachai Production Brigade in Senshi Province, an area of rocky soil, erosion, and poor agriculture. The approximately 90 households in Tachai Brigade operate 144 acres of this hilly land. Through the construction of stone terraces, underground conduits to carry off occasional flood waters, an irrigation system, and the adoption of chemical fertilizers and other agricultural innovations, the farmers of Tachai Brigade were able to raise their grain yields from 1,050 kilograms per cultivated hectare in 1949, to 5,295 in 1965-66, and to 8,220 in 1971 (Perkins and others, 1977, p. 207). This achievement is remarkable in comparison to China's national average of 3,300 kilograms per cultivated hectare.

But the main lesson of Tachai Brigade is self-reliance. For example, after a disastrous rain in the early 1960's washed out all of the stone terraces that had been laboriously constructed by the Tachai farmers, this Brigade adopted the slogan of "three don't wants": Don't want state funds for recovery, don't want state grain, don't want relief materials. This self-reliant theme of the Brigade was entirely consistent with Mao's philosophy, and in 1964 he proclaimed: "In agriculture, learn from Tachai." This slogan is reproduced on dams, bridges, and the walls of homes and public buildings throughout China.

Once Tachai became Mao's agricultural model, it was challenged by Mao's rival, Liu Shao-chi (and his followers), who criticized the Tachai Brigade "for putting politics in the background," and advocated their own agricultural model at Tao-yuan Jing-yan (the Peach Orchard experience). After six years of struggle with the Liuists, who claimed that the Tachai farmers had falsified their accomplishments,* in 1970 Tachai emerged as the national model for agricultural development (Stiedlmayer, 1975). The politics of models represents one strategy for Chinese leaders to promote their favorite policies: "A major strategy is for a leader of a policy-specifying area to cultivate a model unit that actually implements the program that he had in mind" (Oksenberg, 1975). After the model attains success, the political leader draws attention to it through the mass media and by on-the-spot conferences.

"The entire process of sending delegates to on-the-spot conferences at models is designed to arouse a feeling in the conferees that people like themselves have solved problems like theirs under equally trying conditions. It also drives home the principle that with determination, patience, and imagination, they can do as well" (Chen, 1976, p. 144). Thus one important effect of on-the-spot conferences (in addition to providing information about the innovation being studied) is to increase feelings of personal efficiency (the belief that one can control his own future, rather than its being controlled by fate, nature or supernatural forces).

On-the-spot conferences are meetings held at the site of a model which allow participants to actually see the innovation in use by a local unit, to ask questions about how to implement the innovation and what its effectiveness has been, and to consider how the innovation might be utilized in the participant's home unit. Following the on-the-spot conference, the participants report this information to their peers, who then decide whether or not to adopt the innovation, and, if so, how to fit it to their particular local conditions.

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* During 1980, the impressive gains in farm production by the Tachai Brigade again became a topic of dispute in China, when the Peking government charged that the county data, which included Tachai's production, were rigged. These charges were interpreted as an indirect attack on the late Mao Tse-tung.

The Tachai Brigade received 430,000 visitors in 1976 and 400,000 in 1977 (an average of 1,096 per day). A record 30,000 individuals visited Tachai in one day (Perkins, 1977, p. 142). The "Hawthorne effect" of so many visitors on the behavior of the Tachai farmers probably is considerable and must interfere with their farming operations. In recent years, a large dormitory was constructed at Tachai Brigade to house and feed its many visitors. And in the mid-1970's, an animated exhibit of the Tachai Brigade's accomplishments had to be moved from the Brigade headquarters to the county seat town of Hsi-yang.

In 1975 and again in 1976, National Conferences on learning from Tachai in agriculture were held. The second conference marked the beginning of a national campaign to copy the Tachai model, resulting in a reported 10,000 communes and production brigades in 228 counties that claim they are now Tachai-like. The People's Daily has carried numerous articles about Tachai over the years, chronicling its achievements.

Self-Reliance in Dencentralized Diffusion Systems

In the case of the horizontally-diffused innovation mentioned so far, China's Tachai Brigade, a local system responded to a nationally-set agenda of priority needs. The innovative local program was then promoted by the central government through the mass media, and then widely emulated by other local units. So the central government was an essential ingredient in these decentralized diffusion systems (1) in setting a national agenda of problems, (2) in identifying a local model, and (3) in promoting diffusion of the model's innovations. Thus, in one sense, such a decentralized diffusion system as Tachai Brigade is not completely decentralized. But such a diffusion system is relatively decentralized in comparison to such centralized diffusion systems as the agricultural extension services. Decision-making about which innovations to develop and to diffuse, and to whom, is widely shared among the members of the system, rather than concentrated in the hands of a few officials at the apex of an hierarchial organization (like the U.S. Federal government).*

Comparing Central and Decentralized Diffusion Systems

Decentralized diffusion systems seem to have some characteristics in common with each other, and in contrast to a very centralized diffusion system. Table 1 presents some of the main differences between centralized and decentralized diffusion systems (this table is an over-simplification, mainly because it suggests a dichotomy of centralized/decentralized diffusion systems which does not exist in reality).

Most diffusion systems actually exhibit some characteristics of both models. Even the agricultural extension services have some elements of a decentralized diffusion system; for example, peer networks are an important element in the local diffusion of innovations among farmers.** Also, over a period of time, a

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* Thus our present usage follows the conventional definition of the concept of decentralization as the wide sharing of power and control among the members of a system.

** An interesting case of decentralized diffusion in the U.S. agricultural extension service is provided by the major policy reversal of the USDA toward organic farming and gardening, a type of innovation strongly resisted by agricultural experts until 1980, when the U.S. Secretary of Agriculture, Robert Berglund, concluded that organic farming produced equivalent yields with the use of chemical fertilizers, weed sprays, and pesticides, under equivalent conditions, and at generally lower cost. Prior to 1980, organic farming innovations diffused through a decentralized approach among local farmers, opposed by the centralized diffusion system of the agricultural extension service. After 1980, this centralized system diffused organic farming.

TABLE 1.

COMPARISON OF CHARACTERISTICS OF CENTRALIZED AND DECENTRALIZED DIFFUSION SYSTEMS.

Centralized Diffusion Systems	Decentalized Diffusion Systems
1. Centralized control of decisions by national government officials and technical experts.	1. Local control by community officials/ leaders.
2. Diffusion from top-down experts to local users.	2. Peer diffusion through horizontal networks.
3. Innovations come from formal R&D by technical experts.	3. Innovations come from local experimentation by non-experts.
4. Lower-risk innovations that are high in relative advantage.	4. Higher-risk innovations that are lower in relative advantage.
5. Topics that are of low priority to local organizations.	5. Topics that are of high priority to local organizations.
6. Technology-push, emphasizing needs created by the availability of the innovation.	6. Technology-pull, created by locally-perceived needs and problems.
7. A low degree of local adaptation and re-invention.	7. A high degree of local adaptation and re-invention.

diffusion program can move on a continuum between the two extremes to become relatively more or less centralized. This flexibility in designing diffusion systems, or in changing them over time, has important implications for policy-makers who are designing a diffusion system, once they realize that an alternative to centralized diffusion models may exist. We maintain that the degree of centralization/decentralization of a diffusion system should depend upon such factors as the heterogeniety of the adopting units, the nature of the innovations (whether of relatively high or low technology), etc. Fortunately, for present purposes, several decentralized diffusion systems have been described by diffusion scholars, and a number of evaluation studies have been conducted of such decentralized systems. We are in the process of synthesizing these publications in order to identify the common elements found in most decentralized diffusion systems. Eventually we expect to formulate a decentralized diffusion model.

At the present stage of our work, we are able to suggest the following differences between centralized and decentralized diffusion systems.

1. Relatively more decentralized diffusion systems receive a greater degree of local political and economic support than do more centralized diffusion systems.

2. The roles of facilitators in more decentralized diffusion systems differ from the roles played by change agents in more centralized diffusion systems.

3. Mass media and interpersonal communication channels serve different purposes in more decentralized diffusion systems than in more centralized diffusion systems.

4. More centralized diffusion systems are characterized by relatively greater emphasis on the problem (technology pull) and less on a pre-determined

solution (technology push), than are more decentralized diffusion systems.

5. More decentralized diffusion systems promote a wider range of innovations than do more centralized diffusion systems, and re-invention of innovations occurs more frequently in more decentralized diffusion systems.

6. Technical expertise is more difficult to bring to bear to solve technological problems in more decentralized diffusion systems than in more centralized diffusion systems.

To date, little comparative research has been conducted in order to determine the main advantages and disadvantages of centralized and decentralized diffusion systems. We do not believe that either centralized or decentralized diffusion systems are best for all situtations. Instead, we feel that there may be specific conditions under which the diffusion system designed by planners should approximate one or the other of these two models. Future research should attempt to determine just what these specific conditions are. A first, and very important, step is to recognize that the centralized diffusion model is not the only wheel in town.

CONCLUSIONS

We believe that decentralized diffusion may be an important approach that would be utilized in diffusing present-day technological innovations in U.S. agriculture.

Many of these innovations are of a distinctive nature in that they offer a means of avoiding certain of the unfortunate consequences of the chemical technologies that have been diffused to U.S. farmers in the past.

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Background Paper No. 28

CREDIT AND CREDIT INSTITUTIONS AS FACTORS AFFECTING THE LONG-TERM PRODUCTIVITY OF U.S. RANGELANDS AND CROPLANDS

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CREDIT AND CREDIT INSTITUTIONS AS FACTORS AFFECTING THE LONG-RUN PRODUCTIVITY OF U.S. RANGELAND AND CROPLAND*

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During the past three decades credit has become increasingly more significant in U.S. agriculture. Since 1950 interest on non-real estate farm debt and farm mortgage debt has increased from 4.3% of net farm income to 34.3% of net farm income in 1978. Correspondingly, total farm debt as a percentage of net farm income increased from 91% to 428% during the 1950 to 1978 period [14, 20]. Fluctuations in the international and national money markets are having a greater and greater impact on net farm income, commodity markets, and producer production decisions. The pertinence of an inquiry into credit and credit institutions' roles as factors affecting the long-term productivity of U.S. rangelands and croplands would appear to be justified. This paper will examine the current distribution of farm debt to identify the current role of the federal government in agricultural credit, discuss the role of the lender in credit transactions and the resulting implications for soil conservation, describe the impact of credit on producers' soil conservation decisions, and make specific recommendations concerning public policy toward research on the relationship between credit and soil conservation.

Current Role of Government in Farm Debt

The amount of national farm debt increased dramatically during the 1965-1978 period, and the primary source of this credit has been the private sector. The predominate lender for non-real estate farm debt has been commercial bankers. Their percentage of total outstanding non-real estate farm debt has increased from 39.0% to 46.2% between 1965 and 1978 (Table 1). In contrast, the predominate lender in farm real estate debt has increasingly become the Federal Land Bank (FLB). Since 1965 the FLB has increased its percentage of total farm real estate debt from 19.5% to 33.6% in 1978 (Table 2). Significant differences exist in the level of involvement of different private lenders in the two types of farm debt.

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The two primary federal agencies involved in farm credit are the Commodity Credit Corporation (CCC) and Farmers Home Administration (FmHA). The CCC price support loans are a significant component of the commodity support programs [18]. A recent farm policy proposal, Conservation Incentives Program (CIP), has advocated the integration of soil conservation practices with the commodity price support system [2]. Benbrook proposes that producers who voluntarily comply with specific soil conservation practices would receive marginally higher target and support prices than producers not complying. A possible economic incentive to comply not mentioned by Benbrook would be an adjustment of the interest rates or other credit aspects of the CCC nonrecourse loans.

The FmHA loan programs are primarily directed toward farmers experiencing financial difficulty and/or deemed to lack creditworthiness by commericial lenders. Such farms have been affected by environmental disasters, depressed commodity prices, or tight cash flows resulting from high levels of financial leverage [2]. Although consideration could be given to having soil conservation practices as being an eligibility requirement, recognition must be given to the fact that forcing soil conservation practices may further antagonize current cash flow difficulties [4]. Research into the soil conservation practices of FmHA borrowers and the implications of soil conservation requirements to their cash flows should be conducted before such a public policy is implemented.

Implications of the Role of the Lender to Soil Conservation

The primary role of the agricultural lender is to supply debt capital to those producers demonstrating an acceptable level of ability to repay the loan.

Table 1: National Non-Real Estate Farm Debt: Amount Outstanding by Lender on January 1 in 1965 and 1978

Year and Description	Commercial Banks	Production Credit Associations	Federal Intermediate Credit Banks[1]	Farmers Home Administration	Others and Individuals	Commodity Credit Corporation[2]	Total
1965:							
a. Billions of Dollars	$ 6.99	$ 2.28	$ .12	$ .64	$6.33	$1.54	$17.91
b. Percentage	39.0%	12.7%	.7%	3.6%	35.3%	8.6%	99.9%
1978:							
a. Billions of Dollars	$25.71	$13.51	$ .37	$3.14	$8.41	$4.49	$55.63
b. Percentage	46.2%	24.3%	.7%	5.6%	15.1%	8.1%	100.0%

1 Loans to and discounts for livestock loan companies and agricultural credit corporations

2 Although price support loans of the Commodity Credit Corporation (CCC) are nonrecourse loans, they are treated as debts. Borrowers must either pay them or deliver the commodities on which they have borrowed.

3 Rounding error may result in the sum not equaling 100%.

Table 2: National Real Estate Farm Debt: Amount Outstanding by Lender on January 1 in 1965 and 1978

Year and Description	Commercial Banks	Federal Land Banks	Life Insurance Companies	Farmers Home Administration	Others and Individuals	Total
1965:						
a. Billions of Dollars	$2.42	$ 3.69	$4.29	$1.28	$7.22	$18.89
b. Percentage	12.8%	19.5%	22.7%	6.8%	38.2%	100.0%
1978:						
a. Billions of Dollars	$7.78	$21.89	$8.82	$3.98	$21.67	$63.64
b. Percentage	12.2%	33.6%	13.9%	6.3%	34.0%	100.0%

Source: [5]

The credit decision of the lender involves the determination of the amount of funds to be lent and the interest rate to be charged to the borrower. This determination is dependent upon the lender's objectives, the method of loan evaluation, and the criteria used to evaluate the loan applicant.

Crucial to the evaluation of the lender's role in soil conservation is the recognition of the primary objective of the lender and its implications to the lender's lending activity. An investor-owned lender's primary objective is to make a profit from the loan transaction. Farm Credit System lenders must preserve member-patron equity and deliver credit to member-patrons at competitive rates. Extensive lending to poor credit customers is not compatible with the lender's primary objectives. Thus, lenders tend to stress repayment ability and default risk rather than the profitability of the borrower. An essential dimension of the lender-borrower relationship is the recognition of the managerial prerogative of the producer. A lender is an input supplier--not the manager. The role of the lender is not the ranking of investment opportunities of the producer and instructing him/her to invest in specific investments within the farming operation. This traditional relationship may be violated in the case where the borrower is experiencing financial difficulty and endangering the profitability of the loan transaction to the lender. The primary concern of the lender is in meeting their objectives through providing credit to creditworthy borrowers. Thus, public policy directed toward requiring private lenders to enforce soil conservation practices would be very inconsistent with the traditional role existing between the lender and borrower.

The methods of loan analysis and the criteria used in the determination of creditworthiness vary significantly between lenders. The methods of determining creditworthiness range from the sophisticated credit index system of the FLB to the simple ranking of the producer as being an A, B, C, or D creditor with an A representing the highest quality creditor [8].

Examples of the criteria or variables used in the credit analysis are the size of the loan relative to the appraised value of the security, net worth, debt-to-asset ratio, management ability, the ratio of loan payments and other obligations to repayment ability, and the liquidity of assets.

Although lenders may not explicitly require soil conservation practices, the loan evaluation process does implicitly account for soil conservation. The lack of soil conservation reduces the yield potential for different levels of input use and lowers the productivity of the land. Although increased input levels in the form of fertilizer and improved plant varieties may disguise the loss of productivity, a loss of productivity does occur [9]. Higher input levels are required to produce the same level of output. This implies additional input costs and a reduction in the available profit for the repayment of loans. However, research has indicated that soil conservation practices in Iowa will adversely affect initial repayment ability and will hinder grain farmers to a greater degree than livestock farmers [4]. The implications of little or no soil conservation only becomes evident in the loan evaluation process after the producer has not practices soil conservation for a period of years and is then compared to producers who have practices soil conservation during the time period.*

Management ability refers to the ability of the borrower to coordinate human, financial, and physical resources at his/her disposal in an economically efficient manner. Lower productivity in crop production implies a lower evaluation of management ability.

Also, because soil erosion reduces the productivity of the land, the appraisal value of the land would decline relative to land where soil conservation was practices [6]. Since the availability of loan funds is frequently associated with the appraised value of the land, a borrower would be confronted with declining loan funds available to him/her. For example, the maximum the FLB can legally lend has been 85% of the appraised value of the security.

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* Such a statement assumes that the operating and maintenance costs of soil conservation are less than the benefits and is reflected in the producer's profit and loss statement.

However, this does not imply that a producer will be rejected for credit just because of poor soil conservation practices. A major factor decreasing the implicit effect of soil conservation in the loan process has been the rapid land inflation during the 1970's. Plaxico and Kletke have argued that land appreciation has impacts on the wealth position of the landholder prior to the sale. Increased wealth from land appreciation reduces the financial risk level of the borrower and increases the borrowing capacity by providing security [5]. Because of land inflation the borrowing capacity of the producer is not reduced; rather, the rate of growth in borrowing capacity declines.

An additional limitation with respect to the loan process is that the evaluation procedure is based on current cash flows. The process does not take into account possible future changes in input and commodity prices. The long-run impacts of soil erosion are not accounted for in the process. The producer is penalized for the lack of soil conservation practices after the erosion.

The impact of lenders on soil conservation is probably minimal. If soil conservation adversely affects current repayment ability, the impact of the lender may be negative. The ultimate managerial responsibility for soil conservation lies with the farmer and rancher. The impact of credit on these individuals' decision process is the critical area for determining the significance of credit as a factor affecting the long-term productivity of U.S. rangelands and croplands.

The Impact of Credit on Soil Conservation Decisions of Producers

Producers must allocate limited resources among available investment alternatives. Soil conservation is only one of these investment alternatives. To determine the profit potential of investment alternatives, management must (1) determine the capital requirements, (2) forecast the earning, (3) estimate a revelant time period or time horizon for investment evaluation, and (4) identify a realistic analytical model for selecting among the investment alternatives [17, p. 56]. The primary method for evaluating capital investments is capital budgeting, a technique discussed extensively within the agricultural finance literature [1, 10, 14]. The primary influence of credit on soil conservation involves the impact of the cost of debt capital on the valuation of future cash flows and the level of net cash flows available to the producer.

Cost of Debt Capital and Soil Conservation

The cost of debt capital to agriculture has been rising steadily since the 1950's for both farm real estate and non-real estate loans [16]. For example, during the 1950-1954 period the FLB real estate loan rate averaged 4.5%, but by the date of this report the FLB interest rate was 10.25%. The impact of this increase in interest rates can be seen by discounting expected future cash flows. If a dollar to be received 10 years into the future would be valued today, the current value of that future dollar would have declined from 64¢ to 38¢ because of the increase in interest rates—a 41% decline in the current value of that future dollar. Soil conservation measures such as terracing and windbreaks require a large initial capital expenditure with their major benefits occuring several years.later. These conservation measures become less attractive to producers as interest rates increase and shorten the economically relevant planning horizon of the producer. The pattern of the cash flow from soil conservation is not attractive under high interest rates [7].

Accompanying the increasing cost of debt has been a decreasing ability of farmers to pay for recently acquired land from the current earnings of the purchased land [12]. This can be demonstrated by examining the trend toward lower ratios of cash rents to farm value in Wisconsin and the resulting relationship to real estate debt interest rates. During 1950-1954 period, the average ratio of rent to value for farms rented for cash was 7.9%, while the average FLB interest rate was the previously mentioned 4.5%. By 1975-1977 the ratio of rent to value for farms rented for cash was 6.7%, and the average FLB interest rate was 8.6% [16]. Current cash returns to land owner ship relative to value have declined to even lower levels in recent years, and interest rates have continued upward. Combining this factor with the inflation in farm inputs, the pressure on farmers to farm fence row to fence row is readily apparent.

High financial leverage levels for certain producers further antagonizes the problem of meeting current cash flow requirements of credit. Assume a new farm entrant with 30-year amortized loan with an 8.5% interest rate on 75% of the average land value per acre in the U.S. during 1978, plus a 4-year amortized loan with 9.1% interest rate for 80% of the U.S. average machinery cost per acre. Also, assume the new farm entrant and an established owner-operator both have identical corn yields of 101 bushels per acre and receive a price of $2.12 per bushel. In such a situation the new entrant would have lost $90 per acre and the established farmer would have made $102 [19]. Clearly the new farm entrant would have been under considerable pressure to maximize current cash flows. Credit and, in particular, interest rates have probably caused producers to shorten their economic planning horizon and exerted pressure on them to produce as much current revenue as possible.

An additional problem area is the valuation of land based on current cash returns within the capital budgeting context. Although low current cash flows relative to an asset's value is frequently perceived as being an indication that resources should be exiting from the industry, this should not be considered the case with agricultural land. Land is increasingly being perceived as a growth stock with low initial returns, and expectations for capital gains and growth in net returns per acre [12]. Agricultural lenders presently appraise agricultural land on a comparable sales basis rather than the discounted current cash flow method [10]. Capital budgeting analysis using current cash returns to estimate the future cash flows from agricultural land is probably underestimating the future value of agricultural land and soil conservation.

Recently Mitchel, et. al., used capital budgeting to analyze the profitability of terracing agricultural land in Illinois. Their excellent analysis specified how the kind of subsoil, the slope, the type of terrace used, the level of management and the soil erodability affected the profitability of terracing agricultural land [13]. However, their analysis used current commodity and input prices for forecasting future cash flows. In order for capital budgeting to be an effective allocative mechanism, the analysis must incorporate expectations concerning input prices, agricultural demand, and inflation. The complexity of valueing agricultural land should not be underestimated.

Currently, macroeconomic policy is demanding interest rates to perform the major tasks of controlling inflation and intertemporal allocation of resources. Increasingly, interest rates are becoming a public policy instrument rather than being reflective of the time preference of American society. A critical public policy consideration is whether the current interest rates accurately reflect our time preference in valueing the productive capacity of agricultural land. A possible alternative public policy criteria is the safe minimum standard, which has been proposed for use in examining the extinction of wildlife species. Soil erosion, like the extinction of wildlife species, has the characteristics of irreversibility and uncertainty of future benefits [3].

Implications for Future Research and Public Policy

1. Agricultural lenders provide credit to agricultural borrowers meeting their lending criteria. The role of the lender in determining the soil conservation practices of farmers and ranchers is probably minimal. The productivity of public policy or research directed towards the relationship between lenders and borrowers would probably not be high.
2. Public policy and research efforts on soil conservation should be primarily directed toward the farmer and rancher. However, educational activities on soil conservation directed toward lenders may be beneficial. Producers should be provided usable and understandable research on the impact of soil erosion on productivity.
3. High interest rates are probably having an adverse effect on soil conservation because of the decreased present value of future cash flows and current cash flow difficulties of producers. Research on the impact of credit on producer conservation decisions may provide useful information for future public policy.
4. Currently, the federal government is supplying credit through the Commodity Credit Corporation and Farmers Home Administration. The potential of having soil conservation practices associated with these credit programs should be examined. Such a policy could possibly be coordinated with the Conservation Incentives Program proposed by Benbrook [2].

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Background Paper No. 29

EMERGING INNOVATIVE TECHNOLOGIES FOR RANGELAND

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EMERGING INNOVATIVE TECHNOLOGIES FOR RANGELAND

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SUMMARY

Although significant technological progress in range management has occurred during the last three decades or so, there remains much to be done in alleviating key production constraints. Unfortunately, emerging technologies are few in comparison to the number and magnitude of problems facing the range livestock industry of the United States.

There is a great deal of interest among producers and range technicians in short duration grazing (SDG), especially in the application of SDG in the "Savory Grazing Method" (SGM). According to one estimate, more than 300 such systems were installed in Texas from 1975 to 1980. SDG utilizes three or more pastures per livestock herd with relatively short grazing periods (perferably 7 days or less) and deferment periods generally not to exceed 60 days. This concentration of relatively large numbers of animals on a given area but for a short period of time followed by longer rest periods supposedly simulates the grazing activities of pristine mammals; and, consequently is considered by many to be the most "natural" grazing method available. Unfortunately, there is a paucity of research data which allows an objective assessment of SDG. The popular press and proponents of SDG, especially as used in SGM, proclaim the potential of doubling stocking rates (compared to previous carrying capacities), and simultaneous improvement in range vegetation. If so, this increased carrying capacity could significantly improve production output of the typical ranch firm but research will be necessary to evaluate such claims and define cause-affect relationships which regulate success of the systems. It appears that the greatest limitations to SDG are financial (costs of developing physical aspects and procuring needed livestock). However, SDG also appears to hold great promise for increasing production from a substantial part of our rangelands.

Rising costs of energy and equipment, other inflationary pressures, and federal scrutiny of herbicides for range improvement have precipitated interest in development of Integrated Brush Management Systems (IBMS). IBMS are developed within sets of management objectives for resource use, in concert with grazing management strategies, and use brush control technologies to maximum advantage to optimize production from rangeland resources at least cost over a relatively long planning horizon. This approach has led to rediscovery of fire as a management tool and its refinement for application as prescribed burning. IBMS using prescribed burning-herbicides-mechanical methods have been developed for or appear promising on several of the most troublesome brush problems.

Vertically-integrated weed control-revegetation systems for sagebrush rangelands of the western United States are being developed. Apparently, recent requirements for impact statements concerning effects of grazing of public lands is resulting in significant decreases in stocking rates in many areas. These actions coupled with rising improvement costs provides impetus for intensive systems to increase forage production on sagebrush rangelands to meet carrying capacities required for economical range livestock production. In response to this need, weed and brush management (herbicides-prescribed fire)-revegetation systems are being integrated with grazing management. Although presently in only the formative stages, the development of these technologies should be expedited for early implementation.

The progressive loss of productive rangelands to desertification is of global concern, and the need for energy-efficient land reclamation machinery is great. The "land imprinter" is an experimental tillage device developed to build "minipits" of various geometric designs in the soil and to direct runoff to the imprinted land. The minipits are designed to trap seeds and water, and to provide a firm seedbed. Broadcast seeding attachments can apparently be attached to the imprinter. Although the machine has several theoretically attractive features, quantitative performance data were not available. Until such comparative data are available, a detailed assessment of this technology will not be possible.

Although of greater interest a few years ago, various segments of industry and government are actively pursuing the concept of deriving energy from biomass. The appeal of biofuels from rangeland, especially using brush as the primary source, is diminished when productivity of most rangeland areas are considered. Although the brush cover in Texas, as an example, is a primary limitation to herbaceous forage production, biomass requirements of a steam-based source of electric energy would probably require a harvest radius of at least 20 miles. Yet, as we strive to become increasingly energy independent, the potential importance of biofuels connot be completely disregarded.

An important consideration, although not technologies applied directly to the land, are improved technical services for range livestock producers. Continual advances in computer technology has placed modeling of range livestock enterprises within the economic reach of many ranch firm managers. Optimization/simulation techniques offer the producer the opportunity to select enterprises and/or mixes of ventures on an objective, managerially-sound basis. This approach offers the firm manager a reasonable hedge against risk and uncertainity and a high degree of refinement in the decision-making processes related to natural resource use. The present primary constraints to utilization of the technology relates to software availability and producer acceptance as related to understanding of potential of the technology. In the opinion of the author, this technology should be accelerated.

EMERGING INNOVATIVE TECHNOLOGIES FOR RANGELAND[1]

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INTRODUCTION

Since the specific charge underlying this paper is to identify and assess innovative technologies for rangeland, and because the nature of rangeland will certainly be addressed as fulfillment of another major task, the author dispensed with traditional opening descriptions of the resource and its importance. There has been significant technological progress in range management during the past three decades or so, especially in such areas as grazing management strategies, livestock breeding and health, weed and brush control techniques, and watershed management and protection. However, there remains much to be done in alleviating key production constraints, and emerging technologies are few in comparison to the number and magnitude of problems facing the range livestock industry. Range and forage research needs for red meat production were reviewed relatively recently for the National Planning Committee of the Agricultural Research Policy Advisory Committee [26], and those priorities are still valid. Therefore, care was exercised not to simply review state-of-the art technologies, but to isolate new technologies with apparent potential for direct application (or with increasing utility) during the next decade or so. For example, there is considerable interest in the reclamation of rangeland drastically disturbed by strip mining. However, present activities are focused upon applying available technologies (revegetation, fertilization etc.) for that purpose rather than development of new technologies.

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Criteria for selection of technologies for assessment were based on subjective judgment--primarily the author's opinion as to techniques, procedures and potential new uses of rangeland which appear to be stirring the greatest interest among producers, range technicians, and scientists. This procedure builds in an unavoidable bias as a result of the author's geographical area of research emphasis and experience. Therefore, in an effort to broaden the assessment, several persons at locations removed from the author's and with other professional ties to the range resource were queried as sources of expert opinion. Those persons are listed in the acknowledgments. Hopefully, this procedure gave the paper reasonable geographical balance.

QUALIFICATIONS AND INTERPRETIVE CONSIDERATIONS

Consideration of certain salient aspects of rangeland as they affect development of technology and its application to range resource management is important to effective interpretation of assessment statements herein. In contrast to cropping systems where planting to harvest requires less than a calendar year, rangeland is harvested repeatedly through time by secondary producers (livestock, wildlife) which convert primary production (vegetation) to a form of protein that man may directly utilize in his diet. Although secondary production is harvested annually, the primary producers must be tended carefully on the long-term.

Range resources are managed extensively in contrast to intensive management inputs (irrigation, fertilizer etc.) required for successful production of row crops. Thus, by nature of the management requirements of the range resource, research to improve management techniques and strategies requires relatively long time periods for completion. Moreover, research must consider all users and products from the resource as influenced by complex interactions of the biotic and abiotic components which regulate responses of the ecosystem to treatment.

Because rangelands and their management needs vary widely, not only in a geographic sense from the arid and semiarid west to humid southeast and from the cool north to the mild south, but also within a georgraphical region, only generalized assessment of technologies is possible in this paper. For example, the statement of work for this paper indicates that "In discussing how technologies can or might change sustained productivity, the report shall indicate the present status of the productivity on the land where the technologies are to be applied." "Productivity is defined here as the ability of the rangeland ecosystem to sustain production of forage and environmental services such as groundwater recharge, streamflow volume and quality, and wildlife population stability."

It is emphasized that productivity of rangeland depends on the potential of its basic unit, the range site.[3] Since a typical management unit[4] may be (usually is) composed of more than one range site, and those sites may vary widely in relative potential productivity, responses to treatments can only be generalized and expressed in comparative terms. Even then, estimates can be misleading. For example, whereas a 100% increase in sustained productivity may represent a change in livestock carrying capacity[5] from 1 animal unit[6] (AU) per

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[3] Range site is an area of land having a combination of soil, climate, and natural life that is significantly different from that of adjacent areas [7].

[4] In this context a management unit is defined as a discrete area, usually a pasture, with a specific use within the range firm.

[5] Carrying capacity is the maximum stocking rate possible without inducing damage to vegetation or related resources.

[6] An animal unit is considered to be one mature cow and its calf or equivalent. Conversion factors have been developed to equate other kinds of animals to the standard animal unit [7].

15 acres on a deep site in southeast Texas to 1 AU/7.5 acres, it may equate to increasing carrying capacity from 1 AU/80 acres to 1 AU/40 acres in west Texas.

The modes of technology transfer and factors affecting producer acceptance of new technologies is also an important consideration. By virtue of the nature of the resource and of the landowner, technologies are generally accepted and implemented gradually through relatively long time spans. This should not be interpreted as lack of cognizance of the importance of technologies to the range livestock producer, but as relating to the time, effort, and finances required to change his approach to range management (approaches which have usually been tested by preceding generations and adopted as "best" for a particular operation). Ranchers are always interested in "something new" but adapt technologies to fit their specific operation. Direct applications of many technologies occur through an evolutionary process based on actual experience. New technologies, introduced by agencies such as the Soil Conservation Service or State Extension Service, usually are tried by relatively few of the more progressive ranchers. As the word of successes circulates among producers, the general technology may be adapted to an increasing number of operations.

As a consequence of this acceptance mechanism, the most promising technology of 1980 may not be utilized to a significant extent until the 1990's. The impact on range livestock production is really reflected through promulagation of management philosophy in adapting the principles of management to the producer's economic environment. This seriously complicates one's ability to estimate the overall impact of technologies and potential time frame and scale of application, especially when interacting factors (livestock markets, weather etc.) are considered. New and innovative technologies discussed herein have been assessed in the context of this traditional acceptance pattern.

Since use of new technologies on federally-owned lands is essentially mandated by policy, it is difficult, as with private landowners, to project use patterns and potential impacts. A good example is adoption of rest-rotation grazing by the Bureau of Land Management as the major tool for range management throughout the west, essentially to the exclusion of other grazing management methodologies [27]. As land use policies change so can applicable technologies be expected to vary.

Three primary areas will be addressed: grazing management and grazing systems; range improvement systems; alternative uses of range products; and technological services available to range livestock producers.

GRAZING MANAGEMENT AND GRAZING SYSTEMS

Short Duration Grazing

Background

Control of livestock grazing to prevent excessive use of range plants has long been recognized by range resource managers and researchers as critical to improvement of the nation's rangelands. Various schemes of grazing control, premised on the concepts that the degree and frequency of defoliation of forage plants by grazing must be controlled and that periodic removal of all animals from the range (grazing deferment or rest) is necessary to prevent overuse of the plants to the detriment of the range, have been developed. Thus, specialized grazing systems have been recommended as a means to improve range conditions, maintain or improve livestock production, and obtain more uniform and complete use of the range and range plants [30].

Grazing systems[7] have not universally proven superior to continuous, yearlong grazing at conservative (moderate) stocking rates,[8] relative to livestock gains [29]. For example, Pieper et al. [30] recently reported that average weaning weights and calf weights per acre were higher for pastures grazed continuously than for a four-pasture, one-herd rotation system on blue grama (Bouteloua gracilis) range in south-central New Mexico. However, as previously noted by Merrill [29], "the vegetation on the rotation pastures is obviously improving more than that on yearlong grazed area." Further, "it is a reasonable assumption that increased animal production will follow range improvement" [31]. Indeed, there is evidence that grazing systems are capable of increasing net returns to management compared to continuous grazing [28].

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[7] Grazing system is defined as "a specialization of grazing management which defines systematically recurring periods of grazing and deferment for two or more pastures (management units).

There has been considerable interest recently in short-duration grazing (SDG) systems. These systems utilize three or more pastures per livestock herd with relatively short grazing periods (less than 14 days, prefereably 7 days or less) and deferment periods not to exceed 60 days [1]. This system may be contrasted to the more conventional deferred-rotation (DR) systems which are designed to provide each pasture deferment during each of the seasons. An example is the four-pasture, three-herd, deferred-rotation (Merrill) system which allows each pasture 4 months rest followed by 12 months grazing (Table 1). The deferment periods are scheduled to provide rest during critical periods for vegetative growth, development and reproduction. For example, spring deferments are designed to allow establishment of forage seedlings, and restoration of vegetative vigor whereas fall rest periods allow seed set.

Short-duration grazing concentrates a relatively large number of animals on a given area but for a short period of time followed by longer rest periods. The cattle are rotated through a series of pastures several times (perhaps six or more full rotations) per year [2]).

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[8] Stocking rate is the area of land which the operator has alloted to each animal unit for the entire grazeable period of the year.

Table 1. Resting sequence for four-pasture deferred-rotation (Merrill) grazing system.

March 1 to June 30	July 1 to Oct 30	Nov 1 to Feb 28
Pasture		
1	2	3
4	1	2
3	4	1
2	3	4
etc.	etc.	etc.

Description and Present Status

Recent impetus for public attention to SDG has resulted from reports of successes from South Africa and espousement of the "holistic" approach to ranch management by Rhodesian ecologist, Allan Savory [32]. This has given rise to the widely publicized "Savory Grazing Method." The Savory Grazing Method (SGM) is not synonymous, in the strictest sense, with SDG.[9] The Savory Grazing Method also referred to as the "cell system" and encompasses considerably more than SDG. Economics and financing [35], range planning [36] and administration [37], livestock management [38] and other operational factors are apparently utilized to develop an overall ranch management plan of which SDG is an integral part. Savory has developed a rather unique approach to using SDG as a part of his grazing method. His method utilizes SDG with pastures in a cartwheel arrangement (Figure 1) surrounding watering and handling facilities in the hub (Figure 2). The pasture arrangement and handling facilities are designed to minimize "livestock stress" imposed by conventional handling techniques. The principles and primary associated advantages of SGM to vegetation and livestock according to Vaughan-Evans [3], Savory [32], and Savory and Parsons [33, 34, 38] are:

1. Grazing periods during the growing season are short as possible to avoid repeated defoliation and excessively severe defoliation of the most palatable plants. The concept is that overgrazing (utilizing the plants too severely and/or frequently) usually occurs plant by plant,

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[9] Apparently, the term "short duration grazing" was coined by Savory in 1965 [34]. However, because Savory felt that SDG was used to describe various rotational grazing systems which "did not comply with the original principles," he is using the name "Savory Grazing Method" (SGM) to distinguish among systems. Admittedly, the author has observed confusion among range technicians in differentiating among SDG, SGM, and high intensity-low frequency (HILF) approaches to grazing management.

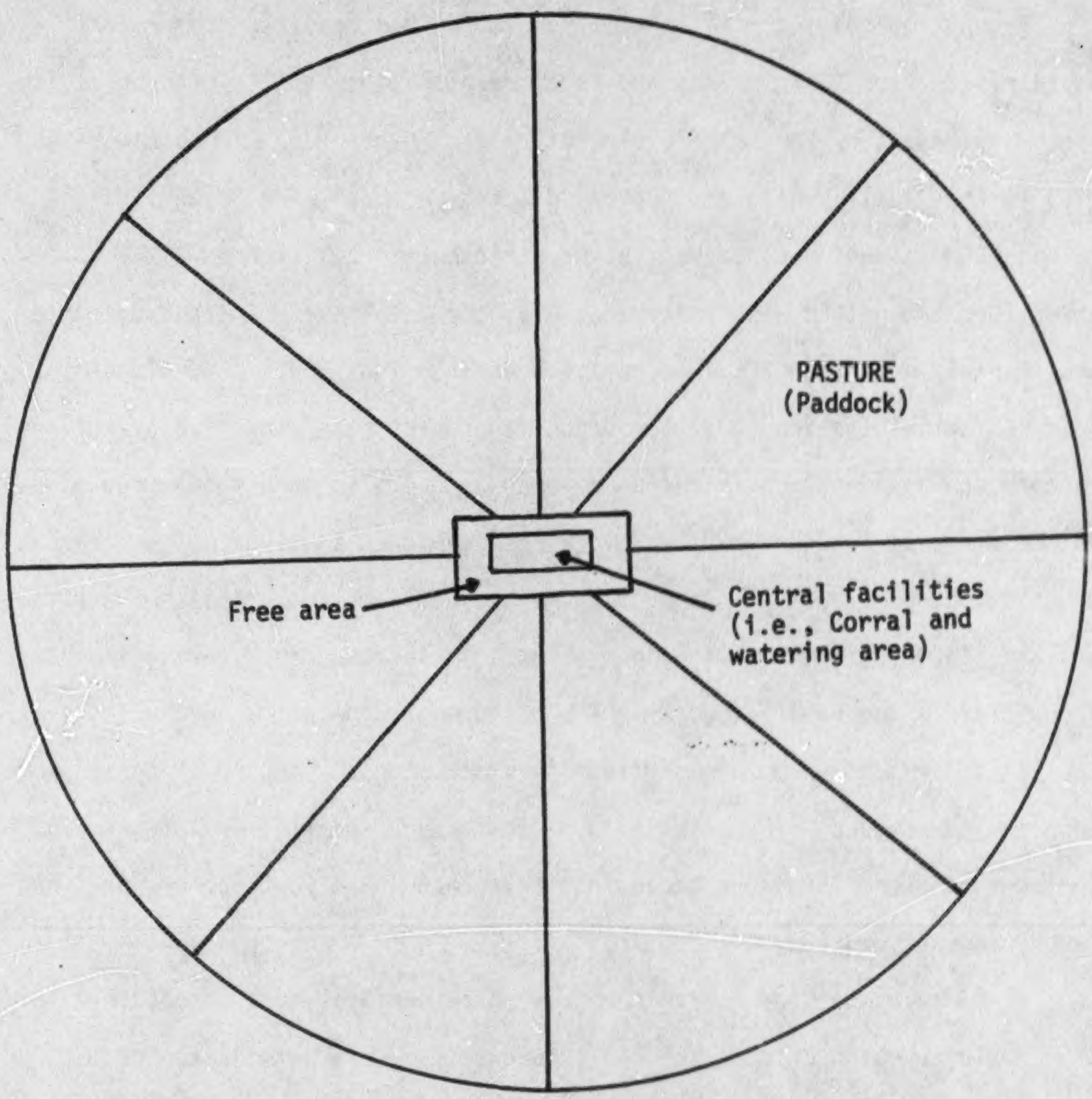
PASTURE
(Paddock)
Free area
Central facilities
(i.e., Corral and
watering area)

Figure 1. Author's perception (greatly generalized) of cartwheel pasture arrangement ("cell layout") used as part of "Savory Grazing Method."

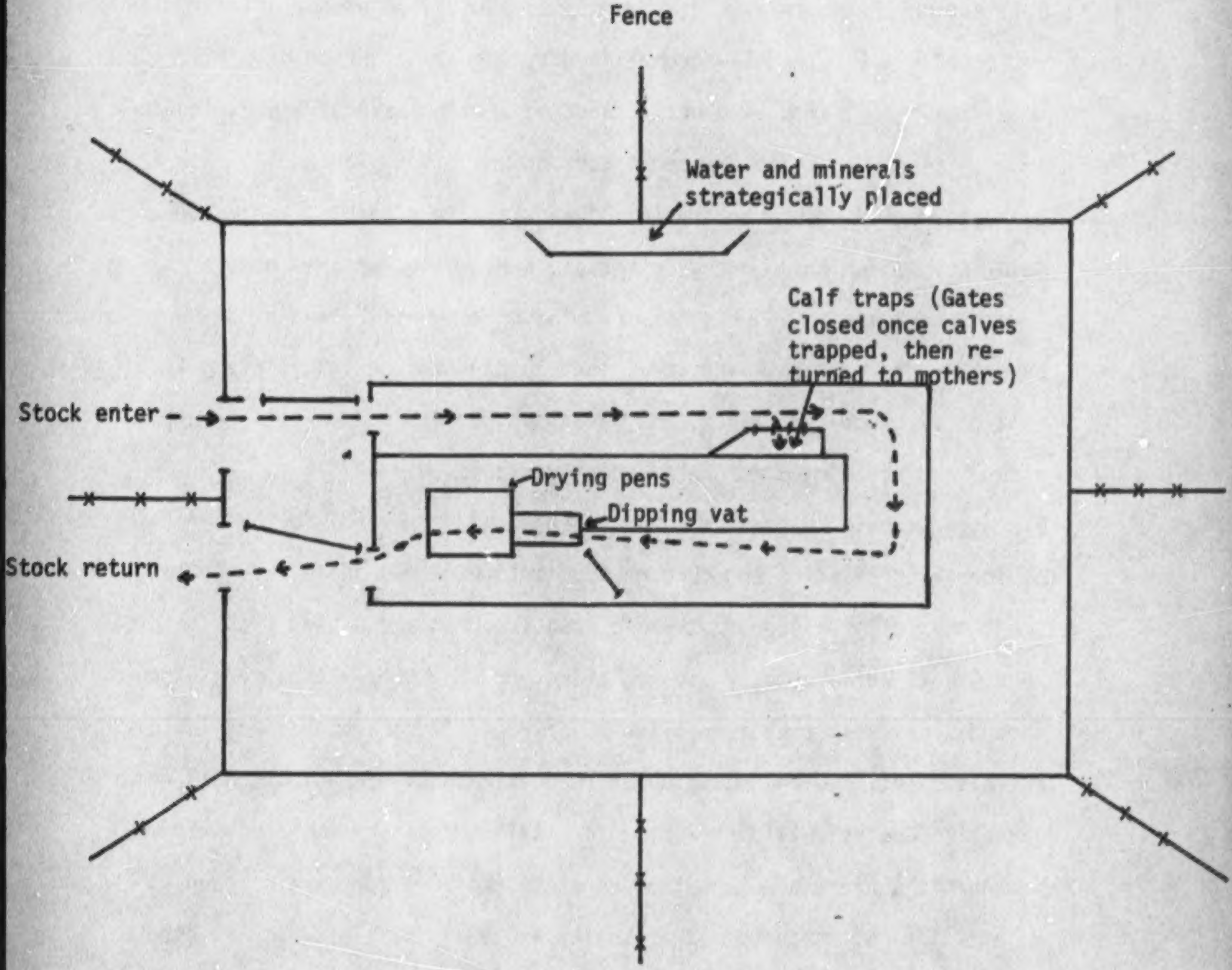
Fence
Water and minerals strategically placed
Calf traps (Gates closed once calves trapped, then returned to mothers)
Stock enter
Drying pens
Dipping vat
Stock return

Figure 2. Simplified layout of hub of cartwheel pasture arrangement (author's perception) to illustrate approach to livestock handling using "Savory Grazing Method."

species by species. Thus, it occurs on ranges which appear to be stocked correctly and well managed but which allow the livestock to occupy an area too long at a given time. SGM is designed to enforce uniform utilization of the forages followed by a rest period adequate for restoration of vigor. This is accomplished by a grazing period of one to three days [34], with as short periods of grazing as possible during the growing season to avoid "second bites" on any given plant.

2. Rest periods are adequate to allow palatable plants to recover from defoliation, replenish energy reserves, and achieve optimum growth. Savory and Parsons [34] suggest that for bunch grass[10] ranges, 30 to 60 days of rest is ideal. They feel that 30 days may be insufficient for full recovery of the plants, and more than 60 days adds little growth and extends the subsequent grazing period excessively.

3. High stocking densities (grazing for a short period) forces eveness of forage utilization and through hoof action of the animals, chip (and open) the soil surface and trample standing dead and unused plant material to the soil surface to provide mulch cover. The hoof action opens the capped soil (soil crust) to allow moisture infiltration and seedling establishment, and the mulch cover reduces rainfall impact and soil water losses. Dung is well distributed for maximum reuse by the ecosystem.

4. Animal performance is optimized since the livestock are allowed to select diets of the necessary quantity and quality. This reduces stress and maximizes yield per acre of livestock.

5. Livestock handling is minimized by using grazing cells in the cart-

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[10] A bunch grass has the characteristic growth habit of forming a bunch or tuft (as contrasted to species which form a sod from runners); examples are little bluestem (Schizachyrium scoporium), big bluestem (Andropogon gerardii) and switchgrass (Panicum virgatum).

wheel with handling facilities in the hub (Figure 2). Careful handling (no roping or whipping) is emphasized to minimize stressing the animals.

As a result of interest in SDG and especially the methods of Mr. Savory and Dr. Parsons,[11] "Savory Systems" have been established on several ranches in the southwest are being researched in several states.

Scale and Time Frame of Application

Scale of application of grazing management systems, implemented at the firm (or management-unit level in the case of federally-owned lands), has traditionally been relatively small when compared to total land area ecologically amenable to such practices. Perhaps this has been a result, at least in part, of the failure of conventional grazing systems to consistently increase livestock production capability of the ranches. Ranch firm size has an important bearing, as it influences available capital, cash-flow relationships, borrowing power etc., on implementation of new technologies. For example, 93% of Texas ranch firms operate with herd sizes of 199 head or less and account for 63% of the state's beef herd [39]. In contrast, only 2% of the ranch firms have herds of 500 or more head of cattle but account for about 20% of the state's beef herd. It is expected that larger ranch firms (>500 cow herd)[12] may implement such a system on only a part of their land area whereas smaller operations (<199 cow herd) may convert the entirety of their operation to the grazing system.

Although Savory apparently does not recognize firm size constraints to implementation of his grazing method, the author has certain reservations concerning the capability of many firms to finance implementation of the technology. Cost of fencing and structures to employ SGM must be considered. As Savory and Parsons [35] pointed out"...because of the large cash outlays involved, careful planning and cash flow budgeting is essential." They then stress that "In general, the problems associated with the development of the Savory Grazing Method are financial and not economic." However, for the ranch manager who depends on a stable minimal cash flow for survival and must depend on loans to install the system, the investment may not be easily reconciled, at least in the short term.

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[11] Savory and Parsons Ranch Consultants, Irene, South Africa.

[12] Ranch firm size is referenced as described by Whitson and Scifres [39] with herd size categories of <200, 200-499, and 500 head or more. Categorization of herd sizes would probably be different for best reflection of operations in surrounding states.

In addition to investments in structural changes, additional livestock are needed to take advantage of reported increases in stocking rates. According to Savory [32], "Our experience has been that doubling the stocking rate has been the rule rather than the exception with properly planned and executed short duration grazing." In the experience of the author, a typical ranch firm as a cow-calf operation can increase herd size by purchasing additional cows (capital outlay), retaining more weaned calves for incorporation into the breeding herd (reduced sales), and/or converting partially to a stocker operation (buy and sell mode). Any of the above options would require an understanding banker for the operator without reserve capital for investment. Obviously, increased herd size is a necessity for SGM or SDG to function properly.

Again, it appears that SDG, and especially SGM, would be most attractive to the larger ranches with reserve capital for investment, the ability to absorb short-term reductions in sales, and/or convert to increasing stocker activities [40]. This feeling is reinforced by Savory and Parsons' [34] statement that "Carrying capacity of range usually increases rapidly under SGM, but financial constraints usually preclude immediate increases in the stocking rate." They feel, however, that SGM has sufficient flexibility to handle varying stocking rates [34].

Once SGM (or SDG) is accepted by a landlower, actual and full implementation requires several years (the author surmises usually less than 5 years), depending on the size of the system and characteristics of the ranch.

Extent of Application

Based on experiences to date, there appears to be no geographic constraints on applications of SDG including its use in SGM. Careful planning is apparently required, however, for its application to mountainous and irregular terrain. Present users are primarily private ranchers but governmental agencies such as the Soil Conservation Service are showing a great deal of interest in the system. SDG has been discussed, relative to problems and potentials, by range scientists for the past 15 or 20 years. SCS workers estimate that about 300 SDG systems were installed in Texas between 1970 and 1975 [57]. However, greatest awareness of the method in the United States has occurred during the past 3± years with the advent of the "Savory Grazing Method." Thus, "cell grazing management systems" (SGM) in Texas are generally less than 2 years old [58].

Potential Impacts

The expectation in the statement of work is that this part of the assessment be addressed more fully than preceeding sections. However, the rate of emergence of SDG and SGM has out-distanced research and practical experience such that this portion of the assessment cannot be based on more than hypothesized responses. Presently, it is accepted that effectiveness of SDG, especially as espoused in SGM, requires an increase in stocking rate (double the original rate is often used [32]). This has stirred interest among some scientists who are concerned that such a system will be detrimental to the rangeland. As put by Grunow [4]. "How one can put up ones stocking rate by 50 to 100%, however, as sometimes claimed for SDG, thereby raising degree of utilization and lowering grass productivity, yet maintaining the sward and animal performance is difficult to understand in the light of present scientific facts." The primary concern is that the increased stocking rate will result in sacrificing the preferred species on the long term while stimulating the less preferred species to greater productivity. These sorts of variations in opinions concerning grazing systems are traditional [31].

On the long term, it appears that SDG as used in SGM has the potential for increasing annual livestock production by at least 50% on the areas to which it is applied; and, based on present experiences and observations, this increase can be achieved without detriment to the botanical composition of the vegetation [5]. Also, based on present experiences which are gounded in little quantitative research, there have been no detrimental influences of SDG on wildlife habitat [59], water yield or quality, or other biological entities in the ecosystem. The entire concept is premised on reinstating ecological balance to the ecosystem [33]. However, it is my opinion that the influence of SDG on wildlife, especially ground-nesting birds and animals with distinct home ranges (such as white-tailed deer), should be investigated in this country. Moreover, it is my opinion and that of others [5], that there should be concern relative to the influence of high numbers of animals per unit area on certain soils during wet periods. Many of the soils of U.S. rangelands have high shrink-swell characteristics, compact readily when wet, and are slow to recover from severe compaction. It would appear that potential for excessive soil compaction exists in those situations, and that the potential negative impacts of "hoof action" should be weighed against the claims of positive effects.

Economic consequences relate primarily to the user, and it is suspected that degree of impact, as previously described, will vary with ranch firm size. It may be more difficult for small producers to implement the system on the short term, but relative benefits accured may be greater in the long run than for the "larger" ranch firm. Rising land costs have made it difficult for ranch firms to expand size of their operations externally. Methods such as SDG may offer a method of expanding operation size internally, and maintain economic viability. Impacts such as on firm tax structure are difficult to predict since the tax framework of each operation is characteristically unique.

The primary constraints on expanding the application of the technology is related to the need for quantitative research data from such systems under field conditions. Presently, the systems are being considered with minimal research backing so that many decisions are intuitive, except for those ranches which have engaged the services of Savory and Parsons, Ranch Consultants. Research constraints range from those concerned with impacts of the vegetation and livestock nutrition to economic considerations. Although SGM has enjoyed successes in other parts of the world, there are still those who voice concern relative to its utility and potential impacts [4]. I believe that the technology should be accelerated but at a rate supported by research findings. Thus, because of the apparent potential of SDG, research on the method should be amplified to ensure that the technology emerges with all critical facets identified to allow appropriate decision making at the firm level.

Present government policies will impact the technology primarily through influence on funding for research and public education, and as they influence management of public lands. Adoption of uniform grazing management policies for public lands [27] could preempt appropriate application of new technologies such as SDG. Moreover, it would appear that lessees of federal lands for grazing would be slow to respond to intensified management approaches, such as SDG, without established incentives.

Externalities of the technology and indirect impacts on natural resource systems appear to be minimal.

VEGETATION MANIPULATION SYSTEMS

Integrated Brush Management Systems

Background

Excessive cover of woody plants, commonly referred to as brush,[13] have traditionally posed one of the primary deterrents to optimizing production from rangeland. Various control methods, primarily mechanical and chemical, have been developed and successfully applied for range improvement lasting varying lengths of time. However, ever-increasing costs of equipment, energy, and herbicides; and, federal scrutiny of herbicide-use on rangeland have accentuated the need for approaches to the problems which are economically feasible, ecologically acceptable, and readily available to management. Moreover, there should be a series of alternatives available to give the land manager flexibility in the decision-making processes concerning range improvements.

The concepts underpinning approaches to coping with excessive cover of woody plants have changed drastically during the past 30-35 years. Initially, research programs were developed to "eradicate" undesirable species such as honey mesquite (Prosopis glandulosa var. glandulosa) [41]. It became obvious that "eradication" was neither achievable nor desirable and the term, brush control[14] was widely adopted.

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[13] Brush is a growth of shrubs or small trees usually of a type undesirable to livestock or timber management, but which are sometimes useful or can be managed for wildlife.

Various brush control methods have been developed, each effective in specific situations or for particular purposes but also with characteristic weaknesses. Therefore, it has become obvious that there is no panacea for the "brush problem." Moreover, woody plants have some values (wildlife habitat, shade etc.) and should be considered as a "manageable" part of the resource.

During the past 5 years, woody plant problems have been approached on a research basis through development of integrated brush management systems (IBMS). These system incorporate available technology or a refined version, and consider new technologies in such a manner as to take advantage of the unique strengths of each method while minimizing the impact of its inherent weaknesses [7]. Integrated brush management systems consider all uses of the resource such that overall production is optimized rather than maximizing returns from one use to the detriment of others, and are developed based on economic feasibility, ecological need and utility for management [9].

IBMS can only be applied most effectively when application is orchestrated with other key practices, especially grazing management. Brush management becomes a futile effort when the range is misused. In fact, IBMS should not be considered until a sound grazing management plan has been developed and usually not until implementation of such a plan. Brush management without grazing management may be more detrimental than beneficial on the long term by simply opening up more land area to be repeatedly overused. Thus, grazing management must be considered an integral part of brush management systems [42].

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[14] Brush control is any practice employed to reduce the influence of brush in the management or use of the land.

Description and Present Status

Much of the present research on IBMS emphasizes use of fire-based systems by careful incorporation of prescribed burning. Herbicide-prescribed burning, mechanical-prescribed burning-herbicide, and prescribed burning-herbicide systems have been developed for difficult-to-manage woody species such as Macartney rose (*Rosa bracteata*) [8]; and herbicide-prescribed burning systems are being studied for species such as whitebrush (*Aloysia lycioides*) and running mesquite (*Prosopis reptans*) [9]. The systems approach has also proven effective on areas supporting excessive cover of perennial range weeds such as spiny aster (*Aster spinosus*) which may be controlled with a shredding-pelleted herbicide system [10], and common goldenweed (*Isocoma coronopifolia*) which appears vulnerable to a prescribed burning-pelleted herbicide system [11]. Low-energy mechanical methods [12], prescribed burning, and herbicides are being studied in systems for management of huisache (*Acacia farnesiana*)-infested rangeland. IBMS are designed to:

1. Reduce dependency on any particular method such as repeated herbicide use. A single herbicide application (or no herbicide use) may be used rather than repeated annual applications [7, 8].
2. Use available technology in a complementary manner (and to take advantages of potential synergisms) such as with prescribed burning and chemical or mechanical methods [7].
3. Maintain or improve wildlife habitat while improving livestock production by applying treatments selectively and in patterns [43, 44].
4. Provide a set of treatment alternatives to the producer for design of specific systems.

5. Be melded into other management strategies (i.e. grazing management systems) for maximum utility [42].

6. Improve the economic framework of brush management by increasing effective treatment life [7] and optimizing output of products [44].

Since some available technologies are used in development of brush management systems, application procedures are established for many of the steps. Fire is essentially a rediscovered tool which is emerging as a technical advance when viewed in the context of "prescribed burning," especially as used in IBMS.

The basic procedures involved in applying the technology include:

1. Setting of clearly-defined objectives for use of the management unit (example, relative balance of livestock/wildlife production).
2. Determining potential of the management unit based on range site potentials as an indicator of optimum levels of production (and constraints to increased productivity).
3. Selection of alternative sets and projected sequencing.
4. Economic projections as a basis of comparison of alternative systems.

The system components (treatments) are installed in the traditional fashion but in a predetermined, planned, orderly sequence. For example, consider a range livestock producer in the Coastal Prairie of Texas utilizing a four-pasture, three-herd grazing system who has determined that Macartney rose is limiting his production level. A synopsis of the application procedures and rationale might be:

1. Use an aerial spray to reduce the competitive advantage of the Macartney rose. Considerations might be:
    a. Apply the herbicide in the fall when potential for spray drift damage to susceptible crops is minimized.

b. Treat the pastures one by one as they are scheduled for deferment from grazing in the fall; thus, spreading the investment over four years, and taking advantage of regularly scheduled deferments to maximize forage response. This also allows the producer to gradually increase his livestock herd in response to the rate of improvement.

c. Apply herbicide in patterns to retain brush for white-tailed deer habitat and reduce total land area sprayed.

2. Use prescribed burning at 18 to 24 months after spraying to remove standing woody debris; reinstate valuable broadleaves damaged or removed by the spray; improve botanical composition of the forage stand by favoring the more productive grasses; suppress brush regrowth which survived the spray; improve the browse value of large, decadent, unsprayed brush; improves grazing distribution; perhaps reduce external parasites; and remove "rough" herbaceous vegetation [7, 8, 12, 16, 45]. Repeat prescribed burning at 2 to 3 year intervals, depending on weather, unless brush regrowth becomes excessive, in which case individual-plant treatments with herbicides or treatment of local areas may be advisable.

Scale and Time Frame of Application

IBMS as recently defined [7, 9] is a relatively new concept; and like the "Savory Grazing Method" impinges on essentially all the range management activities.[15] Although it can be argued that ranchers have long used combination treatments on rangeland (spraying-chaining of mesquite for example), application of the principles of IBMS relative to selection of set of alternatives used in a specific sequence and with a well-defined planning profile to meet specific management objectives has not been documented. Thus, the potential scale of use is difficult to project but should be no less than is now treated by single-methods. It has been estimated that an average of 1.5 million acres of Texas rangeland were treated for brush control annually from 1956 through 1977 [13]. In the opinion of the author, IBMS has the potential for implementation on an acreage of that magnitude annually. Furthermore, according to Klingman [14], Junipers (Juniperus spp.), mesquite, and sagebrush (Artemisia spp.) alone infest 242 million acres of U.S. rangelands.

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[15] Although a four-pasture, three-herd grazing system was used to relate IBMS procedures, other grazing management systems can be used effectively. Short-duration grazing appears to be especially amenable to IBMS. However, there is no available research or field experience to support a discussion of the integration of IBMS into SDG.

Within the ranch firm, scale is determined by management objectives for land use and economic feasibility. Magnitude of investment, impacts of cash flow, and other factors will influence scale of use by any given ranch firm.

IBMS requires relatively long planning horizons for achieving land management objectives. For example, whereas the expected treatment life of a given herbicide spray for mesquite control may be 7 years or less, brush management systems are designed to span 15 or 20 years [7]. Without an established, long-term planning profile, efforts to implement IBMS will become simply sets of treatments applied through time. Although time of application involves continuous activity over 15 or 20 years, this is not to imply that production responses are any slower than with conventional methods. The concept simply strives to protract the traditional production responses while decreasing costs of maintaining an optimum production level and without ecological detriment to the resource or adjacent ecosystems.

Extent of Application

IBMS should be of utility across the broad geographic range of rangelands of the U.S. For the next 10 years, it is expected to receive most attention in states such as Oklahoma, Texas, and New Mexico where the brush problem is a priority concern among producers. IBMS research is still in the formative stages and is being used by few producers in Texas. However, it is expected to be considered for adoption by federal and state land managers as well as by private ranchmen. The systems concept for brush management first emerged in 1975 [8] and began to gain increasing attention in 1978 [15]. Since much of the impetus for the IBMS concept lies in recent federal scrutiny of herbicides and inflationary pressures on producers which are preventing implementation of conventional methods of range improvement, it is expected that the rate of adoption of the IBMS principles will increase rapidly during the next decade. Another factor that has caused emergence of the IBMS concept is recent, renewed interest by producers in fire as a "low-cost, natural" method for range improvement. However, on-going research programs are not adequate, relative to safe and appropriate applications of range burning, to keep pace with renewed interest in the practice.

Potential Impacts

One of the basic objectives of IBMS is to optimize range products on a sustained basis. It was the opinion of Thomas [50] that effective brush management technology could double, even triple, the livestock production on western rangeland. In the research experience of the author, IBMS have the potential to double livestock carrying capacities of many range sites to which they are applied. As examples of the potential of IBMS, it was recently reported that a pelleted herbicide-prescribed burning system presently being evaluated for whitebrush-infested rangeland in Texas increased the livestock carrying capacity from 1 animal unit

(AU) 35-40 acres to 1 AU/12-15 acres in three growing seasons [16]. Based on a 1,000-acre pasture and no change in calving percentage (70%) or weaning weights (425 lb), the system has potential for increasing beef production from about 7,438 to 21,123 lb annually, an increase of 184%. On the Coastal Prairie, stocking rates have been reduced from 1 AU/15-18 to 1 AU/5-8 acres using the herbicide-prescribed burning system. Based on the same 1,000-acre pasture and other criteria used previously, beef production could theoretically be increased from about 17,136 to 43,732 lb annually, an increase of 155%. These estimates are intended only to serve as examples of IBMS potential and not as regional averages.

These relative levels of productivity, within weather fluctuations, are expected to hold as long as the systems are kept operative and management of livestock is maintained at a high level. Further, it is the author's opinion that this particular IBMS allows the range to withstand prolonged dry periods better than does unimproved rangeland.

The primary biological processes affected by IBMS relate to vegetational change. Secondary ecological succession has been promoted by the systems, and it appears that wildlife habitat quality has been improved by the mosaic of vegetation types produced by patterned rather than total brush removal. Increasing the ground cover of perennial native grasses decreases potential for sheet erosion during wet periods and the mulch cover should increase surface water relationships, compared to areas with relatively high amounts of bare ground. Such treatments have been documented as effective for increasing efficiency of water use by range ecosystems based on amount of forage produced per increment of precipitation received [46] which, in turn, increases availability of the forage for utilization by livestock.

Primary chemical and physical properties of the ecosystem influenced by such treatment would be related to the soils. Residual patterns of newer herbicides such as tebuthiuron have not been established over a wide range of conditions. Additional research is needed to clearly define their residual lives. However, at application rates used in IBMS, herbicides such as 2,4,5-T ([2,4,5-trichlorophenoxy]acetic acid) are dissipated in the growing season of application and picloram (4-amino-3,5,6-trichloropicolinic acid) should not be expected to carryover into the second growing season [47].

Human beings have an innate fear of fire, and some have concern over potential impacts on the ecosystem. Much of this concern is relative to soil responses. For the sake of space, I have entertained general responses of soils to fire in the following categories:

1. Erosion potential. The greatest potential for erosion occurs when relatively steep slopes are burned and followed by a high intensity storm. This is of special concern with soils which seal readily and promote overland flow. However, burning of slopes no greater than 5% and in the late winter-early spring to promote early green up and rapid development of vegetal cover has resulted in no erosion problems.

2. Water relationships. Compensating factors are operative relative to water status on burned rangeland. Rangeland bared of vegetation by burning has greater surface interception of moisture, but surface evaporation may also be increased somewhat. However, the greatest difference in water content compared to unburned rangeland is consumptive use of water by lush vegetative growth on burned rangeland. This change in water balance typically does not last beyond the first growing season after burning.

3. Nutrient status. Minor amounts of nitrogen and phosphorus are volatilized by range fires, organic matter may be decreased somewhat

depending on conditons of the burn, and soluble salts (calcium, potassium etc.) are returned to the soil by leaching of the ash [48].

The net result of these effects on the soil have not proven detrimental, especially from prescribed burns which are much less intense than wildlires [7].

No consequences, except at the firm level, have been isolated from use of IBMS but additional research concerning potential management impacts is needed. The primary constraints to implementation of IBMS are primarily economic, political, and technical. Economic constraints lie in the magnitude of capital required to initiate the first (and usually most costly) step in the sequence, regardless of method selected. Federal cost sharing through entities such as Agricultural Stabilization and Conservation Service (ASCS) is of increasing importance, especially for the smaller ranch firms [49]. Political-institutional constraints lie in the potential federal scrutiny of methodology required for alternatives. For example, cancellation or restriction of the use of a herbicide needed to implement a given system at lowest cost could require a shift to more costly methods such as high-energy mechanical approaches. Undue regulation of prescribed burning of rangeland could cause a shift to chemical alternatives. The federal government through the U.S. Environmental Protection Agency has apparently begun proceedings to evaluate certain potential impacts of prescribed burning on federal areas [17].

Technical constraints lie in developing system components as well as studies of treatment interactions. For example, technology underlying the use of prescribed burning must be explored in more depth to capitalize on its maximum potential use. Because of the ecological role of fire, many persons tend to take its use for granted while others, because of negative experiences and the impact of folklore, feel that ultimate consequences of fire are invariably detrimental. Herbicide use must be refined through new application of registered compounds and development of improved compounds. Low-energy mechanical methods for broadcast brush management should be developed and/or refined for use where herbicides and/or fire are not applicable. Economic regulators of system feasibility must be identified for optimum application of IBMS.

The emergence of this technology should be accelerated. Full potential of integrated brush management systems cannot be realized until research has identified potential treatment interactions and sets of viable alternatives are developed.

The externalities of IBMS are reflected in large part as the sum of potential externalities of each step in a brush management program. For example, potential of herbicide drift to a susceptible crop or a prescribed burn escaping and turning to a wildlife must be considered. However, there are also potential positive indirect impacts. As any given management unit within a ranching unit is improved, there is increased potential for improving adjacent management units at a later time. Moreover, improving vegetation of one management unit with the ranch firm should relieve stress on adjacent units and facilitate their improvement. Other occurrences, such as increasing or reinstating stream flow directly benefit users removed from the point of application of brush management.

Integrated Weed Control Technologies for Sagebrush Rangelands

Background

Western rangelands are among the greatest natural resources of the nation. Presently, some 8.4 million cows reside an average of 3 months annually on public lands [60]. Concentration of domestic herbivores has caused shrubs, such as big sagebrush (Artemisia tridentata), to increase in density at the expense of herbaceous species. Once established, the life expectancy of big sagebrush may exceed 150 years [61]. Currently, Environmental Impact Statements concerning the influence of domestic livestock grazing on National Resource Lands are being prepared under court order [62]. Every one of these statements that have been completed has resulted in reductions of 20 to 75% in the amount of grazing permitted on public lands [63]. Thus, it is critical that range forage production be increased on these lands to offset losses in grazing capacity but through range improvement practices that are compatible with environmental constraints.

Description and Present Status

Current research is directed at converting degraded sagebrush rangeland to productive, stable sites dominated by perennial grasses. This has been approached by considering a range of technologies which may be appropriate for integration into effective systems. System effectiveness is determined by economic evaluation, vegetation response and red-meat production, and their influence on a large number of interacting environmental parameters. As with IBMS, this approach applies integrated pest management strategies for range improvement. Researchers are monitoring the influence of the integrated weed control systems on birds, small mammals, game species, reptiles, rare and endangered plant species, watershed characteristics, and cultural resources [63]. Some examples, arranged in order from the most complex to the most simple integrated weed control-revegetation technologies [63], are:

1. Vertically integrated weed control systems.

These systems include combinations of herbicide application (2,4-D [(2,4-dichlorophenoxy)acetic acid][16] for brush management and atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine] for herbaceous fallows) to obtain brush control and herbaceous fallows for competition reduction to allow desirable forage species to become established. Crested wheatgrass (*Agropyron desertorum*) is seeded with a rangeland drill [64].

2. Spray and drill operations.

This system is designed for brush management and revegetation where herbaceous vegetation does not constitute a serious competition hazard. A special rangeland drill with modified openers is used to seed into the standing dead brush.

3. Plow and drill.

The degraded range sites are plowed with a special rangeland plow and seeded with the rangeland drill.

4. Prescribed burning and drill.

A controlled fire is used to remove the brush followed by seeding with a rangeland drill.

5. Grazing management after prescribed burning.

The prescribed burn is not seeded, but the destruction of the vegetation by fire sets off vegetation dynamics the direction of which is shaped by a grazing management system.

6. Grazing management.

Same as above, but no prescribed burn to initiate rapid vegetative dynamics.

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[16] Both 2,4-D and atrazine are registered by the Environmental Protection Agency for various uses on rangeland [64].

7. Prescribed burning and no grazing.

The exclusion of large herbivores from sagebrush rangelands has decided influences on many environmental parameters.

8. Exclusion of grazing animals.

Same as above without prescribed burning.

Scale and Time Frame of Application.

Vertically integrated weed control-revegetation systems are presently in the developmental stages. The alternative technologies are being tested on a large-scale basis at the Gund Research and Development Ranch in Nevada [60]. Each treatment consists of at least a 40 acre block. The higher level technologies have been applied to multiple blocks. Forage production and utilization is evaluated by grazing with cattle.

All range improvement techniques involve a period of deferment or rest from grazing to allow the desirable forage to respond to the environmental potential released by the weed control treatments. The vertically-integrated weed control systems involve a 4-year period of herbicide application, fallow season, seedling year and deferred grazing until after seed ripe for implementation. Any treatment involving seeding requires at least 2 years for implementation.

The sagebrush/grasslands under pristine conditions constituted about 10% of the land area of the adjacent 48 states. There are millions of acres of degraded sagebrush rangelands where one or more of these technologies are vitally needed [63]. Private ranchers, and public land management agencies such as Bureau of Land Management, Forest Service, and State Land Management agencies are the expected users. The most simple of these technologies dates back to the 1930's. However, the most complex, such as the integrated weed control-revegetation system, have just been developed. However, because of the pressing need for improvement of sagebrush rangelands (especially in view of court action relative to grazing restrictions [62], the rate of implementation of these technologies is expected to increase rapidly for the next decade or so.

Potential Impacts

Degraded sagebrush rangelands produce 50 to 150 pounds/acre of herbage in "good" years and 0 to 50 pounds/acre on dry lands [63]. Improved sagebrush rangelands produce 500 to 2,000 pounds/acre of higher quality herbage during "average to good" years and have some production in poor years. The increased production and quality of forage translates to more than just higher stocking rates. The higher quality forage during breeding seasons leads to higher calving percentages and increased livestock production efficiency. The results of the weed control-revegetation technologies are evaluated in terms of their influence on the total livestock production system that exists at the Gund Ranch as a model of such ranching operations in the western range area [63]. Approximately 1 million acres of the 57 million acres of sagebrush rangelands in Nevada has been seeded to crested wheatgrass. This 1 million acres supports 25% of the range livestock grazing in Nevada.

If the range improvement technologies are not implemented, many of the western states face social and economic upheavals [63]. Much of the support for the current Sagebrush Rebellion apparently comes from ranchers driven to despair by current "do nothing" management policies [63]. The reductions in grazing on public lands will cripple the livestock industry, decapitalize rural areas, and erode the tax base for schools and essential service support. This will eventually translate to increased beef, mutton, and wool prices for consumers in the entire country.

The author has depended on informed sources for an assessment of these technologies. However, in my opinion, this technology should be accelerated. The primary constraints appear to be technical, although use of herbicide in some systems may be challenged by environmental groups.

Environmental impacts would be of the same general nature as described for IBMS. Based on knowledge of the environmental impact of each method used separately, any negative influences are anticipated to be negligible, compared to potential environmental and production benefits via vegetation improvement.

The impact of government policies on use and management of federal lands is of a complexity that is beyond the scope of this paper and the author's expertise for analysis. However, the author's informed sources relate repeatedly the influence of requirements for impact statements to preceed virtually every management action on publicly owned rangelands. This area is certainly worthy of additional, in-depth investigation, probably as a separate assessment of policy for management of federal lands as it influences technology implementation.

The Land Imprinter

Background

Much of the world's rangeland has been abused by man's activities to the extent that it is essentially barren. There is concern worldwide about desertification, the progressive drying of land and its loss for productive uses. The problem is not so much one of low and infrequent rainfall as one of inefficient use of available water. Abuse, even complete removal, of vegetation and deterioration of surface soil prevents effective infiltration of rainfall into the soil. Various approaches to reclaim these lands, from use of straw placed in grids in the Tengger Desert of China [65] to development of equipment for water conservation and revegetation, are being investigated.

One implement developed to promote more efficient water use and expedite range reclamation and improvement is the "land imprinter," a tillage machine developed by R.M. Dixon [52]. It is basically a large cylinder about 3 feet in diameter and about 6 feet long. "Half of this drum has a corrugated surface that imprints slots or grooves into the soil which will direct rainfall into the other half of the imprinter" [52]. The other half forms a geometric pattern that has V-shaped bottoms. The primary objective of the implement, according to the designer, is to trap and concentrate rainfall in the impression, prepare a seedbed, and provide a rough surface that retards wind and water erosion. "Minipits" formed by the implement trap seeds and retain water to, theoretically, increase vegetal cover.

Description and Present Status

Although the author has not viewed the machine or results from its use, published photographs and interviews with range-trained persons who have attended demonstrations of the imprinter were adequate for relating the concepts. The roller, fitted with desired imprint capsules, is simply pulled over the land surface leaving the area roughed in various geometric patterns, essentially a network of minipits. The imprinter can apparently be fitted with a broadcast seeded. Small stones and brittle shrubs are apparently crushed into the soil surface which should provide a "mulching effect." Since the imprinter has only one moving part, the device should be energy efficient and easy-to-maintain.

Scale and Time Frame of Application

The land imprinter is experimental and is apparently now being developed for commercial use. It was developed in Arizona, and preliminary performance trials were established in that general area. Should any such implement proven effective, scale would be limited only by land owners' perference and need. Theoretically, the imprinting and seeding are accomplished in a single trip over the area.

Extent of Applications

Technology which will improve efficiency of water use on rangeland, especially in semiarid and arid regions, would have essentially global application. However, the "land imprinter" has apparently not yet found such application. Presumably, it is still being tested and demonstrated by the designer who indicates that related research has been conducted at such separated locations as Wisconsin and Nevada, Arizona, Texas and Montana [53]. Although the concepts are not new, the "land imprinter" has apparently been introduced during the last 5 years. Use rate could not be discerned but present areas of use appear to be restricted to the designer's research and demonstration areas.

Potential Impacts

The results from land imprinting are difficult to assess from the literature since no quantitative data were found [52, 53, 54]. The designer's qualitative assessments are extremely positive. However, the evaluation of several knowledgeable scientists, including one member of an evaluation team for National Academy of Sciences [55, 56] questioned that the "land imprinter" had been proven of adequate effectiveness to pursue as an emerging technology.

Most felt that equal results could be achieved with conventional implements used for range management such as the rolling chopper or with techniques such as contour furrowing. Therefore, the author does not offer a detailed assessment. If the concept is pursued, however, it is recommended that evaluations be conducted through a research program which will publish performance comparisons to conventional methods.

ALTERNATIVE USES OF RANGELAND PRODUCTS

Biomass for Energy

Background

The dependency of the United States on imported oil has stimulated intense interest in both the public and private sectors in developing alternative energy sources. The Department of Energy has developed a biomass[17] fuels program with objectives including use of regionally available forestry and agricultural residues and standing biomass as substitute fuels [18]. Because of the interest in biofuels, a considerable number of documents have recently emerged concerning potential and projected problems with the feasibility of commercializing biofuels. However, most of this information is in the form of papers delivered at various symposia or as in-house agency reports that are difficult to obtain. Moreover, time constraints prevented an in-depth literature review of all ramifications of this broad field. Therefore, the author depended on a relative few papers such as the one by Stout [19] and individual contacts for this report. It takes little effort to identify the topic as a controversial one.

Considering only the land area in Texas which supports woody plants

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[17] Biomass, as defined by Stout [19], is "a form of solar energy resulting from the growth of plants or microorganisms, includes all organic matter except fossil fuels."

(some 56 million acres of mesquite alone [20]) and the concern as to the impact of excessive brush cover on range livestock production, a scheme to convert woody biomass to usuable energy immediately appears, at least on the surface, to have merit--perhaps even a concept that is long overdue in emerging. The principle objective of woody biomass harvesting on rangeland is to remove the brush topgrowth (ostensibly "free" brush control for the rancher) and utilize it by direct combustion as a substitute fuel (for example, to produce steam driven electricity producing plants for urban areas).

Use of mesquite as biofuel is attractive to investigators because of its relatively high Btu content per pound (oven-dry): 8,469 - 9,079 for heartwood; 7,907 - 8,235 for sapwood; 7,043 - 8,176 for bark; and 7,846 - 8,222 for a mixture of stems and leaves [21]. These values are generally higher than the average for dry biomass, about 7,000 Btu per pound [19].

Description and Present Status

The efforts relative to use of woody topgrowth from rangeland as biofuel are in the formative stages with primary emphasis on feasibility of harvesting (including yield estimates), transportation, and utilization by commercial plants. It is anticipated that much of the harvesting technology developed by foresters can be implemented on rangeland. Koch and Savage [51] describe the most recent development in harvesting equipment, machinery and auxillary equipment to recover logging residues as chips. They estimate 1980 operational costs of the harvesting operation, including delivery of chips to a mill, to be about $18 per green ton (including a 30% pretax profit on equipment investment). They noted the impact of inflation on their 1980 estimate by comparing it to the 1978 projected cost of $13.57 per ton of green weight delivered to the mill.

The harvester [51] is a 575-horsepower tracked mobile chipper equipped with a front-mounted felling bar. Performance goal for the machine is about 30,000 tons of green cull wood annually from about 1,500 acres of forested land. Design includes a ground-level cylindrical felling bar which feeds a drum chipper. The chips are apparently easier to handle than woody chunks that are produced by a hammer-type hogging head. The machine was designed to operate primarily on stone-free terrain with slope of 20% or less; harvest 1 acre/hr at 1 mph on land averaging 25 tons/acre (green) of logging residue and standing culls; fell and chip southern hardwood and softwood stems to 12 inches in diameter while moving at 1 mph; mill off the tops of 21-inch diameter stumps to a 6-inch height while moving at 1 mph; pick up and feed the material into the drum chipper; and chip felled stem sections to 19 inches in diameter (depending on stem orientation and notching of large limbs by chain saw to improve feeding). Two companion carrier vehicles ("chip forwarders") are used to localize the chips into inventory piles.

Scale and Time Frame of Application

Scale of application would presumably be relatively large because of investment costs such as for harvesting equipment,[18] owning and operating a wood-burning boiler and transportation of wood from the harvest site to the conversion plant. However, estimates for rangeland would be purely speculative since scale of application would vary for each hypothetical conversion plant depending largely on anticipated output of that plant and availability of biomass surrounding the plant. Wiley and Manwiller [21] presented a simplified but rather convincing argument that a harvest radius of 3 miles in an area averaging 15 oven dry tons (25 green tons) of mesquite fiber per acre could sustain an industrial plant requiring 50,000 pounds of steam per hour for about 10 years. Their prognosis provides a basis for assessing the factors that would impinge on scale of application.

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[18] Investment costs (1980 dollars) per "machine teams" (mobile chipper, two self-powered chip forwarders, and support equipment) of harvesting system system described by Koch and Savage [51] was $470,000.

Realistically, estimates of scale for such ventures should consider woody biomass productivity by range site potential since available biomass at any point depends on site conditions and past management history [22, 23]. According to Whisenant and Burzlaff [22], the most productive range sites (bottomlands) supporting virgin stands of mesquite in the Rolling Plains of Texas yielded about 16.1 tons per acre of green weight. Based on estimates of Wiley and Manwiller [21] and assuming a uniform harvestable area of nothing but bottomland sites, a radius of 3.7 miles would be required to support the hypothetical plant requiring 50,000 pounds/hour of steam.

However, any general area of rangeland will be composed of a mixture of sites varying in potential productivity. In the Rolling Plains, the sites would range from shallow (low productivity) to those of intermediate productivity to bottomlands (high productivity). A reasonable ratio of such sites might be 28:28:34, respectively [22]. Using the estimates of Wiley and Manwiller [21], a mix of sites in the Rolling Plains [22], and virgin stands of mesquite, the harvesting radius for the hypothetical plant becomes about 5.1 miles. However, in the study of Whisenant and Burzlaff [22], shallow sites produced only 1.8 tons per acre of green mesquite biomass, probably not worth the harvesting effort.[19] The deep upland sites supported 8.6 tons per acre of green mesquite.

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[19] According to Koch and Savage [51], their harvester is designed to harvest about 1 acre/hr (1,500 acres/year) and deliver about 20 tons/acre of chipped green material. Thus, harvesting of shallow sites (assuming no increase in fuel efficiency or speed) would decrease efficiency to about 10% of the expectation. Harvesting of deep upland sites would reduce efficiency of output by almost 60%.

It would also not be realistic to assume that vast areas of virgin honey mesquite are available. Past brush control treatments have altered woody plant growth form on a considerable amount of the mesquite area of Texas. For example, 8 years after aerial spraying of deep upland sites on the Rolling Plains, estimated green biomass (converted based on 60% moisture content) was about 0.42 ton per acre [23] compared to 8.5 tons per acre produced by virgin stands [22]. Thus, in the opinion of the author, a harvesting radius of greater than 20 miles would probably be a reasonable expectation to support a plant requiring 50,000 pounds/hour of steam, and to ensure maximum efficiency of potential harvesting equipment. This estimate would also allow consideration of other land uses such as for highways, rural roads, towns and cropland.

Although the time frame for application would be solely speculative, if all necessary technical data were available and a city decided to convert a part of its energy demand to biofuels, the conversion would probably not be completed in less than 5 to 7 years. Maximum usage of available biofuel based energy would probably be possible in 8 to 10 years. Total time frame of usage would depend on economic factors, especially as related to cost of fossil fuels, that would lend marketability to woody fuels.

Extent of Application

The concept was rediscovered and received renewed interest on a national scale in the past 5 years or so. The rate of interest began to moderate about 2 years ago but the topic is still active among various research entities. Based on the development of brush types across Texas [7], consideration of biofuels would probably be limited to east of the 20-inch rainfall zone. Capability for production of brush is reduced as it becomes progressively drier west of this zone. Most likely, the greatest demand for biofuels (should they prove feasible) would be the larger metropolitan areas that are undergoing rapid population expansion. Such areas situated in vegetational areas classified primarily as rangeland include Laredo, Corpus Christi, San Antonio, Austin, Dallas-Fort Worth, and Wichita Falls, Texas and perhaps, Oklahoma City. Houston is near enough forested areas to use biomass from the forestry industry. Presently, the technology is not being applied. Were it to prove feasible, and development would most likely be initiated by subsidiaries of the larger petrochemical corporations. The private rancher would be a participant in the technology as the basic supplier of biomass.

Potential Impacts

Removal of the brush topgrowth by harvesting equipment should have about the same effect as roller chopping or shredding. These practices release forages but on the short term. It is generally agreed that top removal of brush must be repeated at 3 to 5 year intervals to maintain improved range productivity [7, 24, 25]. This is not to imply that the brush would be ready for reharvest by 3 to 5 years after the initial cutting, but that regrowth is adequate to cause range management problems by that time lapse after treatment. The potential impact on the sustained productivity of rangelands where used would vary according to:

1. Frequency of use. Brush top removal increases forage production for only a few years, thus, sustained improvement requires repeated treatment [7]. It also temporarily improves browse value. Since the need for retreatment will occur more quickly than probably frequency of harvest, it is not likely that brush harvesting will improve productivity.
2. Degree of disturbance. Although harvester design has been directed

toward minimizing disturbance, the author has reservations concerning its use on rocky terrain or on soils subject to compaction following wet periods. The gross vehicle weight is 72,000 pounds with ground area contact of approximately 6,740 square inches (approximate ground pressure 10.7 psi) [51]. Compaction could reduce water infiltration and promote runoff. if excessive weight is applied to wet soils.

3. Sites harvested. Since logical candidates for harvest are the most productive sites, attention should be given pattern of harvest. Complete harvest of drainages (preferred sites by whitetailed deer) could cause short-term reductions in deer herd numbers if extensive areas were cut.

In the author's opinion the economic and social consequences would not have significant broadscale impact because of the probability that biofuels on rangeland cannot provide a significant source of energy. The primary constraints relate to the distribution of woody plant stands of adequate productivity to warrant harvesting on most rangeland.[20] Because of these reservations, the author feels that removal of hardwood undergrowth and cull softwoods from forest provide more lucrative sources of biofuels than rangeland. Moreover, site preparation costs and other factors lend greater economic advantage to harvest of these sites. Technology should be accelerated for harvest of these sites with the expectation should it become feasible to harvest brush from rangeland, that those technical advances might be transferred to rangeland.

Economic impacts would theoretically have greatest influence on the landowner and that segment of society that benefitted from energy derived from non-fossil fuel sources. In the opinion of the author (based on appraisal of feasibility of the approach), these impacts would be minimal at the present time.

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[20] A notable exception to this generalization might be the post oak-blackjack oak stands of eastcentral and east Texas. Some of any area probably exceed the productivity, relative to hardwood mass, of forest undergrowth.

The externalities of such technologies should be of no greater magnitude than of any standard range management practices. Under appropriate application, erosion, nonpoint stream water pollution and other typical concerns would probably be of minor consequence.

TECHNICAL SERVICES FOR RANGE LIVESTOCK PRODUCERS

Modeling Range Resource Systems

Background

As the need to understand the complex interactions in agricultural systems became more apparent, the amount of information concerning those systems has increased, and cost/return relationships of agricultural investments have become more dynamic and with a greater degree of risk and uncertainty, interest has intensified in the use of mathematical and pictoral descriptions of the function of those systems by synthesizing available data into models. The advent of sophisticated computing systems offers the capability of modeling systems of increasing complexities. Computer technology is no longer the technical domain of researchers, federal agencies, and private corporations. Recent advancements in computer technology and a significant decrease in cost has provided direct access to the rancher [66].

Description and Present Status

Although mathematical models have been used effectively for many years in agricultural systems research and for specific management problems [6], their potential applications to range management are in the formative stages. Simulation/optimization models have been developed to compare grazing management practices and select the best system of grazing management; and simulation models have been developed for purposes such as decision making at the firm level, to model grazing ruminants, and to test the feasibility of practices such as using a mix of ruminants on rangeland [6]. Models have also been applied to plant growth problems and to situations encountered with fisheries and wildlife. Apparently, one of the most serious constraints to effective modeling of agricultural systems has been a limited data base, and that is expected to largely regulate the rate of advancement in the field of model application for range management.

The modeling approach which appears to hold most promise for range management would be a optimization routine to aid in selection of enterprises (or appropriate mix of ventures) at the firm level. Based on management objectives and production potential of the land, a series of production alternatives (or mixes of alternatives) can be evaluated relative to economic needs of the firm and in light of other firm activities.

Scale and Time Frame of Application

Use of models is not limited so much to scale as to availability of reliable data inputs. The time frame of application is extremely short, depending on the nature of the problem application. With appropriate data inputs and a developed working model, the time frame of usage may require no more than a few days. The rapidity of utility is one of the most desirable features of model usage.

Extent of Application

Applications of modeling are not affected by geographical or environmental variations but estimating the influence of these variations is critical. It has value to researchers in understanding interaction of technical data bits within the context of problem solving on a microscale, for identification of critical gaps in technology, and has utility for decision-makers associated with federal agencies, state agencies, and ranch firms. Currently, the technology is being applied primarily in an emperical fashion but, considering the time that its potential has been recognized, it is increasing relatively rapidly.

Hardward available, including minicomputers and programmable calculators, have put the use of modeling into the reach of the progressive manager of a ranch firm. However, software for such purposes is relatively limited. This technical constraint and the need for public education as to the proper use, interpretation, and application of modeling technology are the present serious limitations.

Potential Impacts

The application of modeling at the firm level has potential for refining and accelerating the decision-making process and have positive effects on sustained productivity of rangelands. The "trial and error" approach to decision making on the long-term may be replaced by short-term simulations to allow choice of the "best" alternative for a given management situation.

The primary constraint to the effective use of modeling, in consideration of constraints cited previously, is a lack of reliable data inputs for the generation of "valid" simulations and development of practical, working models for "real life" production situations. With adequate data inputs, decision makers would be capable of quickly exploring important factors such as cost: benefit ratios of potential agricultural alternatives, the appropriate mix of ventures within a given enterprise, marketing structure relationships, etc. In my opinion, the emergence of this technology should be accelerated with primary emphasis on production:economic alternatives at the ranch firm level.

OTHER TECHNOLOGIES

There are several other areas of developing technologies which were not covered by this report, primarily because of time constraints. One such area of development relates to the range watershed and water conservation. There is increasing research activity relative to increased efficiency of water use on rangeland, water trapping, water quality, and nonpoint pollution. This area of work is critical to our nation's welfare and research on range watershed should be expedited.

Remote sensing continues to advance as a technological potential. A promising use for rangeland is application of remote sensing as part of a regional monitoring system for pasture and range feed conditions.

Another area that is gaining increased attention is nongrass forages for range revegetation. Plant materials centers such as the SCS installation at Knox City, Texas continue to evaluate selections of forbs and browse that may be used in mixtures with grasses or on sites where grasses are not best adapted.

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Background Paper No. 30

EFFECT OF EROSION AND OTHER PHYSICAL PROCESSES ON PRODUCTIVITY OF U.S. CROPLANDS AND RANGELANDS

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Effect of Erosion and Other Physical Processes on Productivity

· Relationship to Recent Technological Developments

W. D. Shrader

ABSTRACT

The effect of erosion and other physical processes on crop production depends on the nature of the soil, on the level of technology available and on the crop that is to be grown. Deep, medium textured uniform calcareous soils are least affected and shallow, acid sandy or clayey soils are much more affected by loss of surface soil. Yields of corn are,in general, reduced more by erosion than are yields of grass or forest.

Soil organic matter, soil structure or tilth, soil water-holding capacity, rate of water infiltration and fertility are affected by erosion. It may be economically feasible to compensate for the loss of fertility through use of fertilizers, but for the other factors, costs of compensation for erosion damage usually far exceeds the benefits. On most soils yields are reduced by erosion regardless of the quantities of fertilizers used.

Most soils that were originally high in organic matter have lost organic matter by oxidation break down since cultivation started. Loss of organic matter may effect yields if good soil structure or tilth is largely dependent on organic matter for its maintainence. Soils in which organic matter is essential

for good tilth are more common in the east than in the midwest and west.

Greatly increased use of fertilizers and of large tractors has encouraged useage of erosive lands and of large regular-shaped fields and has discouraged use of such erosion control practices as contour cultivation and of many types of terraces.

Erosion is a continuing problem on cropland in humid regions because within the planning horizon of an individual farmer, costs of controlling erosion frequently exceed the onsite benefits that accrue to the farmer under systems that control erosion.

Effect of Erosion and Other Physical Processes on Productivity of U. S. Croplands and Rangelands. Relationships to Recent Technological Developments.

Reports of disastrous rates of soil deterioration share space in newspapers with reports of record yields and record levels of production of corn, wheat and soybeans.

We are not on the verge of complete destruction of our soil resources. Neither are we liable to continue to increase crop yields into the indefinite future. We will have to work hard and be lucky to maintain present yields. One of the factors acting to reduce yields is the decline in surface soil depth that results from soil erosion. Erosion is occurring at a socially unacceptable rate, largely because technological advances in agriculture have made it possible and profitable for farmers to produce on rapidly eroding lands. In many cases farming so as to control erosion will result in drastically reduced income for the farmer.

Most farmers are forced by economics to discount the future very heavily. Income in the current year is far more important to the individual farmer than income 20 years in the future. Mortgage payments must be made this year. Society should have a long planning horizon. The public has a responsibility to future generations to maintain the productive capacity of the soil.

Damage from erosion and other factors of soil degradation vary greatly under different conditions. An understanding of the basic soil conditions responsible is necessary for rational planning and action for the preservation of our heritage.

BASIC SOIL CONCEPTS: WHAT HAPPENS WHEN SOILS ERODE?

The effects of soil erosion on soil productivity depend on the nature of the soil, on the level of technology available and on the crop that is to be grown. Soil organic matter is in the upper 6 inches to 1 foot in most soils. Soil organic matter is the source of most of the soil available nitrogen and a large part of the plant available phosphorus. Soil organic matter aids development of a desirable soil structure and its presence makes soils easier to till. Severely eroded soils lose most of the soil organic matter. Thus, unless nutrients lost by erosion are replaced, yields of grain crops are very low on all eroded soils. However, fertility can be replaced through fertilizers at a price and some soils are reasonably easy to till even when low in organic matter. Such soils, when adequately fertilized produce fair to good yields of grain crops even under conditions of severe erosion. On soils that are shallow to rock or clay, or have some other unfavorable subsoil, yields of grain crops are usually severely reduced regardless of the quantities of fertilizers used.

Soils with favorable structure even when eroded, are more common on neutral to calcareous soils in the midwest and west than on the more acid soils of the eastern United States.

In the more humid regions, soils are commonly acid and subsoils are poorly suited for crop growth. Such soils are frequently shallow to clay or a hard pan, or a zone that is toxic for plant roots. Crop yields are usually severely reduced by erosion on such soils. If the cause of the yield reduction resulting from erosion can be identified and corrected, be it increased droughtiness, lower fertility, or soil toxicity, the yielding capacity of the soil can be restored. However, aside from restoring fertility elements, it is seldom economically feasible to amend the soil sufficiently to compensate for the damage caused by erosion. The costs are more than the increase in yield is worth. On such soils the usual practice is to shift to a lower value, more tolerant crop. Growth of southern pine on old cultivated fields in the southeastern United States is a widespread example of such a practice. Pine grows about as well on eroded areas as on uneroded.

Different plants have different growth habits, and thus are affected differently by any soil change.

Corn is a full season crop. Where subsoils favor root growth, corn roots can extract all available soil moisture to a depth of 5 to 8 feet to obtain the 25 to 30 inches of water that corn requires for maximum growth. Winter wheat makes its growth prior to the hottest part of summer and will make a satisfactory crop on 15 to 20 inches of moisture. Many of the grasses will make a satisfactory growth over a wide range of climatic and soil conditions.

Any change in soils that reduces the water available to a corn crop, whether through a reduction in waterholding capacity because of a reduction in soil depth or because of reduced water infiltration because of deteriorating structure, can be expected to be reflected in reduced corn yields. Under the same conditions wheat yields can be expected to be reduced less than corn yields and fescue yields will likely be reduced less than wheat.

ROLE OF SOIL ORGANIC MATTER

Throughout the central part of the United States, the major corn producing soils developed under prairie vegetation and originally had surface soils ranging in depth from about 6 to 16 inches that contained from about 2 to 6 percent organic matter.

In addition to loss of surface soil and organic matter to erosion, many soils have lost large amounts of organic matter by oxidation under cultivation. The higher the original level of organic matter, the faster the rate of decline. The lower the original level, the slower the rate of decline. A study by Bartholomew et al (1957) showed that soils in Iowa that contained 6 percent of organic matter in 1917 lost 11 percent by 1953. Fields that were in continuous corn from 1917 to 1952 lost more than fields that were in a corn-corn-oats-meadow-meadow rotation.

The higher the yields and the quantities of refuse returned to the land, the less the decline in organic matter. A study by Morachan (1966) on a loess derived soil in southwestern Iowa that had 2.4 percent organic matter in the surface required an annual application of 8 tons per acre of corn stalks to maintain the 2.4 percent organic matter over a 10-year period.

These data are cited to emphasize that soil organic matter is lost from cultivated land by other mechanisms than erosion.

Soil organic matter is a dynamic soil property. Levels of soil organic matter are always moving toward an equilibrium level depending on the rate of additions to the soil. At the time of settlement, the organic content of soils was in a state of equilibrium that had several thousand years to become established. When the soils were cultivated, varying portions of the vegetation was removed from the land and aeration was faster than under native conditions. Under cultivation it was seldom possible and almost never economically feasible to maintain soil organic matter levels at the high levels encountered under prairie vegetation.

The extreme case of soil organic matter loss occurs on areas of peat and muck that have been brought under cultivation. In Florida, in the Belle Glade area, about half of a 10-foot peat deposit has disappeared in the past 50 years. Under native conditions, the peat accumulated at a rate of about 1 foot in 400 years. Under cultivation, it disappears at a rate of about 1 foot in 10 years. On this extreme condition, if present trends continue, this area, that is now one of the most valuable agricultural areas in the country, will be destroyed within the next 50 years.

On most mineral soils, the prospects are less grim. In Iowa or Illinois, for example, a soil that contained 6 percent organic matter in 1939 had average corn yields of about 40 bushels per acre. At present, this same soil may contain 4 percent organic matter and have average corn yields of about 130 bushels per acre. Throughout most of the country, declining soil organic matter levels have been accompanied by constantly increasing yields during the past 30 years. This does not indicate that yields have increased because organic matter levels are declining. Rather, yields have increased despite decline in organic matter levels because of the introduction of new technologies. Improved crop varieties, greater quantities of fertilizers, and better balanced fertilizers, use of better weed and insect and disease control have all contributed to yield increases.

The roll of decline of soil organic matter in imposing a yield ceiling is hard to separate from the other changes that have taken place. Some trends can, however, be identified.

ROLE OF ORGANIC MATTER IN MAINTAINING SOIL TILTH

Soil tilth is a general term referring to the ease with which a soil can be cultivated. Soil tilth is determined by soil structure. A desirable soil structure is a soft or mellow, well developed, crumb-like structure. A soil with such a structure is easy to till and on it a good seed bed is easy to prepare. Such a soil readily absorbs rainfall.

Soil structure is affected by soil organic matter and also by soil colloids, soil organisms, and by cations, such as calcium, on the exchange complex of soil colloids.

The beneficial effect of organic matter on soil structure is well documented in studies by Alderfer and Merkle (1941) De Boodt et al (1961), Elson and Lutz, (1940), Martin, (1942), Martin, (1945) and Page and Willard, (1946). Improvements in soil structure that result from additions or organic matter are, over the range and amounts and kinds of crop residues that are available on farms, usually directly proportional to the quantities of residues added. The more crop residues that are returned to the land, the higher the degree of soil aggregation that results. Likewise, the greater the loss of soil organic matter, as through erosion, the greater the decline in soil structure.

Studies in New Jersey by Prince, et al, (1941), and in the midwest by Bartholomew, et al, (1957), show that addition of manure over long periods of time resulted in increased soil organic matter levels, or at least a less rapid loss of soil organic matter than on fields where no manure was used.

Soil colloids affect the degree of soil aggregation in that the higher the percentage of clay in non-lateritic soils--soils of temperate regions, the higher the degree of soil aggregation at least in the range of soil textures from loamy sands to clay loams. The effect of percent clay on soil structure is more pronounced on low organic matter soils and less pronounced on high organic matter soils.

The effect of differences in percent clay is confounded with concurrent differences in the calcium level of the soil. Calcium, the most abundant divalent cation in soils, is a flocculating agent and a high calcium content of soils is frequently associated with a well developed structure. Improvement in soil structure and of crop yield through application of large quantities of finely divided calcium carbonate (sugar lime) have been observed by DeBoodt, et al, (1961). Interactions of cations, colloids and organic matter are not well documented but high levels of calcium have been observed to improve soil structure over a wide range of organic matter levels and soil textures.

Causes of differences in soil structure are complex, but some patterns can be identified.

It has been noted:

1. Soil structure is improved with increases in calcium on the soil exchange complex to the point where calcium carbonate is present in the soil. Throughout most of of the United States, the range in percent calcium saturation of the exchange complex parallels a range of pH values from about 4.5 for a calcium percentage of 40 percent or less, to a pH of 8.3 for 100 percent calcium saturation.
2. Soil structure improves with increases in clay content. This increase in aggregation with increasing clay may not extend into the clay range, but is important over the range of textures from loamy sands or silts to clay loams or silty clay loams.
3. Soil structure improves as the soil organic matter is increased. Soil erosion through removal of organic matter results in a decline of soil structure.

The guidelines indicate that acid soils low in clay, and low in organic matter would have very poor structure. Observations indicate that such is the case, as in the studies of Elson and Lutz, (1940), and Kemper and Koch, (1966).

Conversely, soils high in organic matter, high in divalent bases and of medium texture, would be expected to have good structure and they do, as shown by Morachan,(1966), and by Morachan, et al,(1973).

EFFECT OF SOIL STRUCTURE ON CROP YIELD

In some instances, crop yields are increased by treatment practices that improve soil structure, as in studies by Baver and Farnsworth, (1940). DeBoodt, et al, (1961), DeLeenher, (1958) and Jenny,(1933). In other instances, soil structure is improved and yields are unchanged. In some instances, yield declines accompany improvements in soil aggregation as shown in the final years of the southwest Iowa study reported by Morachan, et al, (1972).

On acid soils, low in clay, there is evidence that yields are correlated with soil organic matter contents or to crop residue additions up to soil organic matter levels of at least 3 to 5 percent, as is evident in the studies of Prince, et al, (1941) and of Strickling, (1950). In general, under conditions where poor soil structure prevails, any practice, such as the addition of lime, or of organic matter, can be expected to improve soil structure and yields.

On medium textured, calcareous soils, there is evidence that yields of large seeded crops, such as corn and soybeans, are not related to soil organic matter content over the entire existing range of percentages from a trace to 5 or 6 percent. Studies of Engelstad, et,al, (1961), Morachan, (1966), Moldenhauer, and Onstad, (1975), and Shrader, (1974) support the above statement.

Crop yields on soils where soil structure is largely dependent on organic matter content would be expected to be more affected by erosion than on soils where soil structure is more dependent on soil reaction. Such appears to be the case in all of thestudies referred to in this section.

In general, soils with poor structure can be expected to be damaged more by erosion than areas with good structure.

Most of the forested soils of the eastern United States are acid soils, low in clay in the surface soil, and low in organic matter. These soils have poor soil structure and any measure that may improve structure can be expected to increase crop yields.

RATE OF SOIL FORMATION AND DEGRADATION

Jenny,(1933), cites a study of rate of soil formation on the Kamenetz fortress in the Ukraine. The fortress was constructed in 1362, of calcareous slabs, and by 1930, soil had formed, or accumulated on the level areas to depths ranging from 10 to 40 cms. This soil had a humus content of 3.5 percent and a clay content of about 50 percent. This rate of soil formation is in the range of about 1/2 to 2 inches per hundred years.

Recent studies published in Soil Taxonomy, (1975), present evidence that "accumulation and turnover of the organic matter in surface soil are rapid. Radio-carbon age (mean residence time) of the organic carbon is mostly a matter of a few (1 to 10) hundreds of years." From the standpoint of soil genesis or from a geological standpoint, a few centuries is a short time, but from a soil management viewpoint it is a period of considerable duration.

Exact figures have limited meaning because the evidence of soil formation is complex and also may be obscure. The nature of a soil at a given time depends not only on how long formation has been taking place but on the parent material, the climate, the vegetation and the topography.

As an example, the late Wisconsin till plain in northern Iowa was exposed to weathering about 12 to 15 thousand years ago. Tall prairie grasses have been dominant over most of it for about the past 3,000 years. Locations can be found where neither erosion or deposition have taken place, on which there was about 12 inches of a dark brown surface soil that had about 4 percent organic matter at the time of settlement about 1850. This soil may be leached free of calcium carbonate to a depth of 30 inches. Oxidation has occurred to a depth of 10 feet. The medium textured glacial till is of uniform composition to a depth of about 30 feet. The soil can be defined as being 12 inches, 30 inches, 10 feet or 30 feet in depth, depending on what criteria are used.

Ordinarily, organic matter in the surface soil is the index of development with which most people are concerned. As noted, a period of at least a few centuries is required for it to develop. A dark colored surface soil is a common soil characteristic in the midwest, but is of little value as an indicator over large sections of the southeastern United States. In this region, the surface soils are commonly some shade of light gray or yellow and were low in organic matter when first cleared of timber. Such soils may be regarded as being worn out by farming, when in fact they were "worn out" by soil development. The processes of soil development can make the soil a better media for plant growth but extreme development is usually destructive and makes for a less desireable media for growth of plants.

Man's activity can ruin the soil, but he also can, and over large areas has, greatly improved the soil so that it is much more productive now than at the time it was first farmed. A set of definitions of soil formation could be written so that a given soil could be defined as having developed in the 40 years or 200 years that it has been farmed.

Also, under most commonly considered criteria, man can and does destroy faster than either man or nature can create. Loss of surface soil by erosion is the most widespread process by which our lands are being degraded.

RATES OF SOIL EROSION

In humid regions, most erosion takes place on sloping cropland. On land under natural cover, erosion is most active on semi-arid rangeland. According to Langbein and Schumm, (1958), erosion rates are highest where the annual effective precipitation is between 10 and 14 inches.

One of the highest rates of sediment deposition reported in the country is for a 83-acre watershed near Dow City, Iowa, where for the period 1941 to 1949 deposition averaged 153 tons per acre per year for the entire watershed.

It is probable that the 153 tons of soil erosion per acre per year is exceptionally high.* However, many fields in this region lose in excess of 100 tons per acre in individual years.

As reported by Spomer, et al, (1976), watersheds near Treynor, Iowa with maximum slopes of about 15 percent, that were in contoured but not terraced continuous corn, lost an average of 20 tons per acre per year for the period 1964 to 1973. Losses ranged from 6.7 to 99 T/A/yr over this ten year period.

On a Barnes soil, on a 6 percent slope, at Morris, Minnesota, Mutchler, et al, (1976), report a 10-year average soil loss of 15.4 tons/A/yr on fallow land, 7 tons/A/yr under continuous corn and only .01 ton/A/yr under hay.

Large numbers of erosion measurements have been made since about 1935, covering a wide range of soil, climatic and cultural conditions. Various ones of these measurements will be discussed in the later sections of this report.

Changes in soil structure, soil organic matter, water holding capacity, soil depth, water infiltration rate, soil fertility and available water are the principal soil factors subject to manipulation by man. Changes in salinity of soils as a result of improper irrigation practices are important but are outside the scope of this report. Soil fertility is subject to sudden and dramatic change through the application of fertilizer. Water available to plants can be increased very quickly if irrigation is used.

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* From Summary of Reservoir Sediment Deposition Surveys Made in the United States through 1965. USDA. Misc. Pub. No. 1143.

Other soil properties--soil structure, soil depth, soil organic matter and infiltration rates can only be changed relatively slowly. In general, the rate at which these properties can be caused to deteriorate greatly exceeds the rate at which they can be improved.

Erosion by removing the surface soil reduces soil depth, lowers the content of organic matter and may result in poorer soil structure and in reduced water infiltration rates.

Research on soil erosion control on a national scale started with an appropriation of $160,000 for fiscal year 1930. Within the next few years 10 experiment stations were organized to study causes of soil erosion in the United States. On these stations many of the plots were in banks of runoff plots about 1/100 acre in size, but others were in watersheds varying from a fraction of an acre to several square miles in size.

Because of erratic rainfall, results varied widely from year to year, but over periods of years patterns of erosion emerged.

In recent years, many of the runoff and erosion installations have been closed, but studies with rainfall simulators have been and are being used to give a quick measure of the effect of a given practice on erosion rates.

All available data on erosion rates have been incorporated into the Universal Soil Loss Equation which evaluates the effect of climate, soil, topography, land use and cultural practices on erosion over a wide range of conditions.

As described by Wischmeier and Smith, (1978), the Universal Soil Loss Equation is reliable for estimating average erosion values for large areas and for long periods of time but is less accurate for small areas over short periods.

RATE OF CHANGE OF ORGANIC MATTER LEVELS

Data on rate of change of soil organic matter levels is fairly extensive, In general, the higher the original level of organic matter, the more drastic the decline in organic matter on cultivated land.

Studies by Bartholonew, at al, (1957) in Iowa show that under comparable cropping (from 1915 to 1953) soils that were originally high in organic content lost more organic matter than soils that were low. Loss was also related to cropping systems and treatments. Organic matter losses under continuous corn were greater than under a corn-oat-meadow rotation. As shown by Barnhart and Shrader, (1979), losses are also related to disposition of the crop residue. On a soil with an initial organic matter content of 4.5 percent, fifteen years of continuous corn from which only the grain was removed resulted in a soil organic matter loss of 7 percent. Over the same period removing all top growth resulted in an organic matter loss of 12 percent.

Over the period 1888 to 1948, as described by Woodruff, (1949), a soil on the Sanborn research plots at Columbia, Missouri, lost about 60 percent of its organic matter content under unfertilized continuous corn but lost only 8 percent under a manured rotation system.

More recent studies with higher fertility and resulting higher production of residues show that organic matter levels can be maintained under a variety of farming systems. Moldenhauer, et al, (1967), found that the organic content of an Iowa soil with an organic content of about 4.0 percent was maintained under a system where continuous corn was grown with an annual application of 167 Kg/Ha of N. Similiar results were reported by Morachan, et al, (1972). In New York, Baldock and Musgrave, (198 reported that the organic content of the soils in their study were maintained by high fertilization over a range of cropping systems.

Studies of relationships between soil organic matter levels and crop yields appear contradictory. DeLeenheer, (1958), reported that in Belgium, 1 percent organic matter for each 10 percent clay in the soil was essential for maximum yields. Moldenhauer and Onstad, (1975), report that corn yields on a deep loess derived soil in western Iowa are independent of organic matter levels. It is this apparent contradiction that made necessary the explanation of the causes of soil structure in the introductory section of this report. Organic matter is one cause of soil structure and is a critical factor in some soils.

Soil structure is important in crop production but exceedingly difficult to assess accurately by laboratory or field tests.

One soil property that is related to soil structure and that can be measured quickly and accurately is volume weight of soil. There are numerous studies that include a measure of volume weight but only a few that are concerned with the relationship between volume weight and soil productivity. A study by Hageman and Shrader, (1979), in Iowa illustrates some of the difficulties of such studies. A comparison was made between the volume weight of soil that had been in continuous corn as compared to soil from a corn-oats-meadow-meadow rotation from 1958-1977. Even after 20 years of widely different use and crop yield, the difference in volume weight within any one plot obscured most of the volume weight difference that might otherwise have been noted.

Soil, after 20 years of continuous corn, had a bulk density of 1.17 g/cm^3 as compared to soil from the rotation plots which had a bulk density of 1.13 g/cm^3. Yields of corn under continuous corn even with 180 pounds of N per acre averaged about 10 percent lower for the past 10 years than yields of rotation corn. This was not in agreement with results obtained by Shrader, et al, (1965), or with New York studies of Baldock and Musgrave, (1980). It was, however, in agreement with results reported from Wisconsin by Higgs, et al, (1976).

On some soils changes in soil structure and soil organic matter that are associated with different cropping systems, are associated with changes in productivity. On other soils or at levels of difference in soil properties there is no apparent relationship between the measured soil properties and yield.

The studies cited verify the following observations concerning soil organic matter:

1. Soil organic matter is a dynamic soil property that is always tending toward a state of equilibrium that is dependent on the rate of removal and on the rate and nature of additions.
2. It is very difficult, under cultivation, to maintain the soil organic matter content of soils that were originally high in organic matter but it is easier to maintain levels of organic matter in low organic matter soils.
3. Soil organic matter levels are easier to maintain, or decline less rapidly on highly fertilized or manured soils than on soils that are not fertilized.
4. There is no simple general relationship between soil organic matter content or trends and crop yields. On some soils a certain level of organic matter appears to be essential for maximum yields. On other soils organic matter does not appear to be essential. It is probable, that for any given crop and soil, there is a critical level of soil structure. There is almost no data on the limits of this critical value or what level of organic matter is needed to produce the desired structural condition. There is not, at present, an entirely satisfactory method to measure soil structure.

EFFECT OF EROSION ON CROP YIELDS

In addition to changes in surface soil depth that result from erosion, land leveling, terrace construction and other soil moving activities profoundly affect the soil surface. Construction of a set of terraces to modern design, on a 10 percent sloping field, may expose the subsoil over a third or more of the land surface. Surface soil can be stockpiled and returned but this is not the same as the original undisturbed soil and is expensive. Current costs of stockpiling and respreading 12 inches of top soil is in excess of $4,000 per acre.

Soil productivity problems arising from land-leveling activities have generated a number of studies of the effect of surface soil depth on crop yields. These studies supplement the limited number of studies directly concerned with erosion. These land leveling studies confirm the statements made previously concerning the effect of soil properties on yields response. On deep calcareous to neutral medium textured soils, damage to crop production by surface removal can largely be corrected with additions of fertilizers. On acid, shallow soils, crop yields usually cannot be restored to the original level regardless of the quantities of fertilizers used.

The studies cited indicate that on deep calcarious soils with about 18 to 30 percent montmorillonitic clay, tilth is adequate for the successful growth of a variety of crops on soils devoid of organic matter. Costs of fertilizer and of seed bed preparation may be higher, but with existing feasible technology, yields can be about as high on an eroded as on an uneroded soil. Organic matter is desireable on these soils but it is not essential for crop production.

In the United States soils high in divalent cations, such as calcium, tend to be much more extensive in the west than in the more humid east. Thick deposits of loess extending into the midwest are other extensive sources of favorable soil material as are also the medium textured ground moraines of late Wisconsin glaciers.

Not all soils in the west have such a favorable subsoil. Also, under some conditions it is not economically feasible to compensate for loss of surface soil even when it may be technologically possible to do so. Dasmann, (1968), reported that 589 million acres of rangeland in the west were severely eroded. Eroded rangeland sites are much more difficult to restore to a desirable range condition than are uneroded sites.

As stated by Renard, (1980), the problem on the rangelands of the southwest is severe and has progressed to such a level that the remaining soil is of insufficient depth to provide an adequate reservoir for moisture storage for forage plants. Moisture stress is the single most limiting factor for forage species. Given adequate moisture, responses to N and P can be appreciable although the economies are marginal at best in most parts of Arizona, New Mexico, Utah and Nevada.

Research on the effects of erosion on soil productivity is essentially nonexistent in the southwest.

It is obvious that erosion does effect productivity. Renard, (1980) estimated that erosion rates of one inch of soil in 30 to 50 years occurs on small watersheds.

Erosion studies started in the 1930s, nearly all indicated that grain yields declined drastically as a result of erosion. One exception was at LaCrosse, Wisconsin, where Hays, et al, (1948), reported the results of 8 years of corn and hay yields on severely eroded and moderately eroded plots on Fayette silt loam, a medium textured soil developed on deep loess. Corn was grown in rotation with up to 3 years of alfalfa. Yields of corn on severely eroded land were much less than on moderately eroded land at the beginning of the study, but after 8 years, corn yields were about the same on severely and moderately eroded plots. In this instance the principal fertility needs were phosphorus, which was supplied in modest fertilizer applications and in manure, and of nitrogen which was supplied by the alfalfa. Later studies have shown that where the principal damage of erosion was loss of fertility, yields could be restored, but on soils where erosion damage was to tilth, to water holding capacity, to a reduction in rooting depth or infiltration rate, yield reductions persisted regardless of fertilizers used.

In the northwest, erosion is very rapid in the Palouse. Hans A. Krauss, State Conservation Agronomist, Soil Conservation Service, Spokane, Washington, states that local field data showed that the decline in wheat yield averaged 2.5 bushels per acre for each inch of topsoil that is lost. He stated that 20 percent of the cropland in Whitman County, Washington, has lost all of its surface soil and that long-term erosion has reduced wheat production by 39 percent. It is his opinion that this decline in production is masked by increases in yields from adoption of other advanced technologies.

In Oregon, Alben and Cushman, (1962), report that soil thickness over basalt, which ranges from less than 2 to over 5 feet, affects wheat yields and response to fertilizers. In Washington, Pawson, et al, (1961), reported that yields were not particularly sensitive to organic matter content and soil depths as long as soil depth exceeded 16 inches and organic matter content was greater than 4 percent. Below these values there was a reduction in yield when either value decreased.

In the Great Plains, wind erosion is the dominant erosion problem west of the 99th parallel in Nebraska, Oklahoma and Texas, and west of the 100th parallel in Nebraska, South Dakota and North Dakota. Water erosion emerges as the major erosion problem in the eastern portions of the Eastern Great Plains States.

Data in this region is limited in extent and in quality concerning relationships between erosion and crop production. In addition to studies already cited, the study of Carlson, et al, (1961), concerning corn growth on a surface soil and a subsoil and of Hass and Willis, (1968), are of interest. In general, these studies confirm previous statements that most of the effects of erosion in this region are fertility effects.

Examples of modern studies that show severe reductions in yields with erosion under high rates of fertilization are more numerous from the eastern as compared to the western United States.

On the Atlantic Coastal Plain, Thomas and Cassell,(1977), found the most important soil variables influencing yield ranked in order of importance were 1) Surface soil thickness, 2) level of plant-available P, 3) bulk density, 4) available water-holding capacity, 5) percent organic matter, and 6) level of plant-available K.

On the soil in this study the depth of surface is important because it indicates the depth to 60 percent Al saturation. A concentration of 60 percent exchangeable Al is toxic to roots of most plants. The depth of surface is related to rooting depth which in turn is related to plant-available waterholding capacity. The relationship between surface soil depth, available waterholding capacity and plant growth is summarized in the following table:

Depth of Surface Soil (cm)	Available Waterholding Capacity (cm)	Dry Matter 1975-76 Average kg/ha
26	3.2	5,902
39	5.2	7,397
45	6.4	9,135

On a nonirrigated field, on these soils, waterholding capacity is critical. Even the highest waterholding capacity of 6.4 cm. is less than a third of most of the better soils in the corn belt.

During years of above-normal rainfall, or where irrigation was available, results might be different.

A similar study involving some of the same soils was reported by Phillips and Kamprath, (1973). An indicator crop was grown in soil cores on which an uneroded soil was compared to an eroded soil. All soils were heavily fertilized. Growth was about one-half as much on the eroded as on the uneroded soil. Root penetration was limited to the surface soil, presumable because of the high level of exchangeable Al in the subsoil.

A watershed study at the Southern Piedmont Conservation Research Center USDA-SEA-AR by Langdale, et al, (1979)[b] indicated that at current non-irrigated corn production levels in the southern Piedmont, each centimeter of eroded topsoil costs the producer 150 kg of corn grain per hectare per year. Corn yields on severely eroded, slightly eroded, and uneroded soils averaged 36, 75, and 92 bushels per acre respectively over three seasons with widely varying weather.

Another study by Langdale, et al, (1979)[a], suggested that crop yields may be economically produced while nearly eliminating soil erosion.

On a watershed with an average slope of 3.4 percent,soil erosion (estimated by the Universal Soil Loss Equation) under conventional tillage without conservation practices exceeded 30 tons per acre per year. Under a no-till system erosion was reduced to an estimated 0.58 tons per acre per year.

A study in west Tennesee by Buntley and Bell, (1976), compared the effect of erosion on estimated yields of major crops on three widely different soils.

Memphis silt loam is a medium textured soil formed on thick loess deposits. It is similar to the Fayette soil referred to in the earlier study in Wisconsin by Hays, et al, (1948).

Grenada silt loam has a restrictive zone fragipan in the subsoil.

Brandon silt loam is shallow to sand and gravel. All crops were grown with recommended rates of fertilizers.

Results of the Buntley-Bell study are summarized below:

Soil & degree of erosion	Crop Yields				
	Corn bu/a	Soybeans bu/a	wheat bu/a	Cotton lb/a	Fescue tons/a
		Memphis Silt Loam, 2-5% Slope			
Uneroded	110	40	54	1060	4.2
Eroded	105	36	52	1030	4.2
Severely Eroded	95	32	48	940	4.0
		Grenada Silt Loam, 0-5% slope			
Uneroded	95	40	53	940	4.0
Eroded	85	30	46	875	3.7
Severely Eroded	70	24	40	750	3.2
		Brandon Silt Loam, 2-12% Slope			
Uneroded	80	30	49	815	3.6
Eroded	70	20	47	750	3.3
Severely Eroded	45	16	38	535	2.7

Yields were lowest on the Brandon soils and percentage decrease in yields with erosion was the highest. On Memphis silt loam yields on severely eroded land was 86 percent of yields on uneroded soils. On Granada soils the corresponding figure is 74 percent and on Brandon soils 50 percent.

Fescue yields on Memphis soils were only reduced 5 percent by erosion as compared to Brandon soils on which there was a 25 percent reduction.

This study illustrates that the effect of erosion on crop yields depends not only on the level of technology available but also on the nature of the soil and on the crop that is to be grown. A thorough knowledge of the characteristics of different types of soils makes valid predictions of erosion effects possible.

In most instances the economic value of an erosion tolerant crop is lower than of a crop that is severely affected by soil erosion. Widespread use of fertilizers in the United States has greatly reduced the deleterious effect of erosion on crop yield on some soils. However, even with adequate fertilization there is a moderate to severe reduction in crop yields or an increase in costs of production of the principal food and fiber crops as a result of erosion on most soils in the United States.

AGENCIES RESPONSIBLE FOR RESEARCH

From the review of literature presented it is apparent that USDA-SEA-AR and state experiment station personnel are responsible for most of the research in this field. Some studies are beginning to come out of the Economics, Statistics and Cooperative Service but their work is limited by the lack of appropriate data. Leadership in modeling work in the area of soil erosion, land use and production problems is currently under the leadership of Dr. Earl Heady, at Iowa State University, Ames, Iowa. This work is being financed by a federal grant.

The very extensive soil survey program is a cooperative program between states and the Soil Conservation Service with the federal agency assuming most of the interpretation and publishing responsibilities and furnishing a major share of the monies for the field work.

Essentially all work in the field of soil and water research is a cooperative effort between federal and state agencies. Many publications contain both federal and state authors.

Private companies have little work that deals directly with the effect of erosion on production. However, industry does a vast amount of research on their products. This research may have a great effect on erosion and/or production. Work on herbicides, insecticides, or on farm machinery are all at their present stage of technical development largely because of research and development work in the private sector.

These same branches of industry also finance large quantities of research at agricultural experiment stations. For example, John Deere and Co. financed some of the pioneer work in minimum tillage. Grants by industry to the appropriate departments at agricultural experiment stations are commonplace. This cooperation between the universities and industries has enabled the universities to greatly expand their graduate training programs and their research findings. It has also furnished industry with needed information at a bargain price.

Criticism has been leveled at the universities for ties with industry because of the danger of loss of objectivity in the research work. It is beyond the scope of this paper to judge whether or not such criticism is justified. However, it should be mentioned that too much reliance on private funding may not be desirable because private funding of research is usually on some definite area or problem of interest to the sponsor. If the investigators are engaged in privately funded research they may not be free to be concerned about problems of much greater importance to the public.

The problem of the effect of erosion on production has received so little attention largely because it is a complex problem involving a number of disciplines and requiring a number of years for solutions. Such problems are not well suited to privately financed research. Few companies or organizations have the breadth of concern or the research budgets needed to handle such problems.

In like manner, the interests of individual agricultural experiment stations tend to be too parochial to encompass the range of conditions that need to be considered.

USDA-SEA-AR PROGRAM*

The 1979 program of the Agricultural Research Science and Education Administration, United States Department of Agriculture, in the field of erosion control is being conducted at the following locations:

Tuscon, Arizona
Fort Collins, Colorado
Watkinsville, Georgia
West Lafayette, Indiana
Morris, Minnesota
Oxford, Mississippi
Columbia, Missouri
Sidney, Montana
Chickasha, Oklahoma
Pendleton, Oregon
Pullman, Washington.

Erosion studies using rainfall simulators, studies of erosion from surface mined lands, erosion under different degrees of minimum tillage, studies of the effectiveness of various mulches, including slate, and the influence of soybeans on erodibility of soil are some of the studies in progress.

Modeling work on sediment yield and disposition is being done at Purdue University as is a continuing re-evaluation of various aspects of the Universal Soil Loss Equation.

None of the projects deals directly with the effect of erosion or soil depth on crop yields.

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* 1979 Annual Report, Soil, Water and Air Sciences Research, USDA-SEA-

EFFECT OF NEW TECHNOLOGIES ON SOIL PROPERTIES

New, improved crop varieties,greatly increased use of fertilizers, of herbicides and insecticides, increased size of farm equipment and development of new types of farm equipment have all entered agriculture within the last two decades.

New varieties of most crops have increased potentials for higher yields of better or more uniform quality of product. Modern short-stem wheat varieties, for example, can make use of higher rates of nitrogen and produce much higher yields than was possible a generation ago. Older, longer stemmed wheat varieties lodged badly when more than modest quantities of nitrogen were used. New corn varieties tolerate higher stands than older strains and can thus utilize higher levels of fertility and of water then was possible in past years.

Thicker stands, faster growth and higher crop yields favor erosion control. Erosion occurs on sloping, partially vegetated lands. Thus the heavier the vegetative cover and the quicker it is established, the less the erosion. However, erosion is much less under permanent grass or trees than on any cultivated field. As better varieties and use of more fertilizers have made it profitable to farm sloping soils that were formerly marginal, these new technologies have encouraged use of erosible lands that previously were in grass or trees.

Production of higher yields can mean a slower rate of decline of soil organic matter because the soil organic matter level is a function of rate of organic additions. The more residues returned to the land, the higher the level of organic matter that will result. As more growth is produced now than in the past. more residues may be available. If, however, the residues are also harvested, as for example, corn stalks removed for silage, the actual quantities of residues returned may be less than in past years.

Herbicide and insecticide use has increased greatly since 1960. Increased use of herbicides has reduced the need for tillage for weed control, but elimination of weeds may leave the ground more bare and more subject to washing than in the past.

Residues left on the land surface are one of the most effective erosion control measures available. Crop production with surface residues is possible only if weeds can be controlled with herbicides.

Increased use of insecticides has resulted in higher yields and increased intensity of production. In some instances, control of insects by chemicals has been substituted for control by rotations. The western corn root worm, for example, can be effectively controlled by either rotations or chemicals.

If small grain and meadow crops follow corn, erosion is less and the equilibrium soil organic matter is usually higher than under continuous corn. However, if soybeans follow corn, the western corn root worm is controlled but erosion may be more rapid than under continuous corn.

Larger, more powerful tractors make seed bed preparation easier and make possible more timely farm operation than was possible in the past. The larger equipment has aided production on all land but has probably, because the land is usually harder to till, aided production on eroded land more than on uneroded areas. In as much as the larger machines have encouraged crop production on eroded areas that otherwise might be in permanent vegetation, the introduction of larger power units has resulted in increased erosion.

Terrace systems that were designed for 4-row equipment are frequently not suitable for 6-8-row equipment. There is a tendency to remove the older terrace systems. Because of high costs and uncertainty concerning returns, many of the old systems have not been replaced with modern terraces.

Contour farming aids in erosion control on cultivated land but usually requires that some point rows be used. Point rows could be tolerated with 2-row or 4-row equipment but are too wasteful of land and time when 6-row or 8-row equipment is used.

Larger tractors work more efficiently in large square or rectangular fields than in small irregularly shaped areas. Thus, fields are consolidated whenever possible, eliminating the fence rows as barriers to wind and water erosion and as havens for wild life.

Large scale equipment makes it possible for the farmer to quickly chisel or disc land as an emergency control measure when wind erosion starts. The large equipment also enabled him to fall plow more of his land than was formerly possible, thus increasing the threat of wind erosion.

The new technologies do not necessarily result in increased erosion. They can be used to develop land use systems in which erosion control is much better than in past years.

Various types of systems with less than conventional amounts of tillage offer promise of better erosion control.

No-till systems involve growing of a corn, sorghum, or soybean crop in the stubble of the previous crop with no disturbance of the land except for planting. Weed control is achieved solely with herbicides. In modification of this method early weed control is with herbicides and late control by cultivation.

The no-till method is used, not only following a crop such as corn, where the dead crop residue is left on the surface to control erosion, but also in meadow and pasture crops where the grass or legumes are killed with herbicides and the grain started without any other land preparation. The erosion equation of Wischmeier and Smith, (1978), incorporates research that estimates that erosion under no-till is half of what it is under conventional tillage.

To date, no-till systems have not been widely adopted by farmers. The principal reasons probably are that, 1)yields frequently average slightly lower than under conventional farming methods, 2) costs are about the same as costs of conventional systems 3) problems of fertilizer application and distribution are more difficult under no-till than under conventional schemes, 4) weed control by herbicides depends on proper rainfall to activate some herbicides. If the herbicides fail, recourse must be made to conventional systems. 5) special planting equipment is required for the no-till system. (This equipment is expensive and may replace equipment that is still in good condition.) 6) damages from erosion are not always immediately apparent and the planning horizons of many farmers are too short for them to be concerned about long term goals.

Reduced tillage programs involve any of numerous practices that leave more trash on the surface than is left by a mold board plow and which commonly substitutes additional herbicides for some land manipulation. Use of the chisel plow to replace the mold board plow is a common example. The chisel plow leaves approximately half as much trash on the surface as is left under no-till systems. This residue is an aid to erosion control. However, if, as frequently happens, the chisel plowed land is disced prior to planting, most of the erosion benefits of the system are lost.

TYPES OF STUDIES AND ADEQUACY OF DATA

A representative sampling of the studies that deal directly with the effect of erosion on crop production under modern conditions have been cited in this report. Even when all related studies on land leveling and other surface modification studies are included, the list is not impressive. Only a few soils under a very limited number of climatic and cultural conditions have been studied.

Studies that evaluate the effect of erosion on yields are of the following types.

1. Watershed studies where the complete hydrological cycle, soil condition and crop yields are monitored

for a sufficiently long period--10 to 20 years or more for average results to begin to be valid. These installations are very expensive to install and maintain. All of the presently active installations of this type are largely financed with Federal Funds. The research watersheds as described by Spomer, et al, (1973) are of this type.

2. Studies of the effect of soil depth on yields of a given crop or crops.
    a. Under field conditions of natural erosion.
    Erosion conditions are determined by field examination. Plots are established on soils of known depth and yield records are obtained. The samples may be at random or on a predetermined soil condition to cover a range of soil depth conditions. Analysis of the data is usually by some type of multiple regression. Studies of Henao,(1976), Engelstad and Shrader, (1961), and Peperzak, et al, (1959), are of this type.
    b. Surface soil depth is adjusted mechanically as in land levelling or by mechanical removal of a given depth of soil and yield data obtained are related to soil depth.
3. Data from runoff plots. There have been large numbers of small runoff plots throughout the country. These plots were usually about 1/100 acre in size and rainfall, runoff and erosion were monitored in detail. Data from these plots was used extensively in generating the Universal Soil Loss Equation. These plots have been of use primarily in evaluating the effect of a given practice on erosion

rates rather than the effect of past erosion on current yields. However, they have also furnished some information regarding erosion and yields.

4. Rainfall simulator studies at times on the established runoff plots and at times on temporary runoff plots in larger fields have been extensively used to generate data on the effects of a given practice on erosion rates. Yield information as a function of soil depth has usually been only an incidental part of these studies.
5. A large number of estimates of yield, soil depth relationships are made. The most extensive and probably the most reliable data are the yield estimates that are published in the modern county soil survey reports. Yield estimates are given of every slope and erosion phase of every soil type in the report. These estimates are based on the soil surveyors observations in the field, on limited amounts of farmer interviews, on county and township average yields, and on any other data of which the report authors may be aware. These estimates are as good as the current state of knowledge and vary widely on reliability. They are based on historical data and thus may fail to properly credit any new techniques that have not been generally adopted by farmers. These estimates are generally conservative but are by far the best estimates that are available on any individual field basis.

As of February 1980, soil surveys gave been completed for about 1,300 counties. Mapping has been completed but reports have not yet been published in another 350 counties. Mapping is in progress in about 500 counties. About 66 percent of the United States has modern soil surveys.

Estimates of erosion rates under a wide range of soil and climatic conditions are derived from the Universal Soil Loss Equation as described by Wischmeier and Smith, (1978). Estimates of erosion are made from the equation A=RKLSCP where

A is the computed soil loss in tons per acre
R is a rainfall and runoff factor
K is a soil erodibility factor
L is a slope-length factor
S is a slope-steepness factor
C is a cover and management factor
P is a support practice factor, such as terracing, contouring or strip cropping.

The values used in the calculation are based on all pertinent data. The values are believed to be reasonably accurate for the range of conditions for which actual data is available but less accurate as interpolations are made beyond the data. This equation, while very useful in projecting estimates of rates of erosion to a large number of conditions, has no provisions for directly evaluating the effect of erosion on production.

The estimates have proven satisfactory for most medium textured soils in the continental United States on slopes of 3 percent to 18 percent, but are not adapted for use on cropland on extremely steep slopes such as are encountered on some parts of the world.

PRACTICAL APPLICATIONS

Publications have been issued by agricultural experiment stations that contain information of use to technicians and farmers on productivity of different soils and have some information on effects of erosion on productivity of one or more soil types.

One such study is by Fenton, et al, (1971), on productivity levels of some Iowa soils. This report contains estimates of crop yields on all major Iowa soils over the existing range of slope and erosion conditions. The yield estimates are based on the best available data but are estimates only for most soil conditions and by the present time (1980) are obsolete.

Another approach has been taken in Missouri by Scrivner and Brown, (1979)*. They have devised a production index based on soil properties. This index reflects differences in surface soil depth. On a clay pan soil, Mexico silt loam, they estimate that as surface soil depth decreased from 12 to 0 inches, the productivity index decreased from .71 to .54. In 1978, measured corn yields decreased from 110 to 84 bushels per acre over this same range of decrease in soil depth.

Illinois Circular 1156, Soil Productivity of Illinois Soils, issued by the University of Illinois, Department of Agronomy, Urbana, Illinois, is similar to the Iowa publication of Fenton, et al, (1971)

* Scrivner, C. L., J. R. Brown. Productivity, Pedology, and Fertility. Paper presented at Seventh Soil-Plant Analysts Workshop, Bridgeton, Missouri, November 6, 1979

A number of modeling studies involving erosion have recently been completed or are in progress. An example is a study by Kasal, (1976), in which soil loss, fertilization and land use constraints were evaluated. Rates of erosion were computed using the Universal Soil Loss Equation. Very little firm data was available for the effect of erosion on production. An economic modeling study on the effect of soil depth on corn yield by Hagen and Dyke, (1980), is in process of publication. This study is likewise dependent on estimates of the effect of soil depth on yield rather than on actual data.

Computer technology and modeling techniques in the economic sector appear to have outstripped accumulation of data in the agronomic research area. Techniques now exist to optimize use of resources on a national or even world-wide scale, providing reliable data from the agronomic sector is available. Relatively small differences in physical data can, when expanded to national models, lead to some widely different conclusions.

No estimates are available for most soils concerning the effect on crop yields of declining organic matter or of changes in soil structure that occur independent of erosion induced changes.

Formal models now include the CREAMS model. (Chemical, Runoff, and Erosion from Agricultural Management Systems), which has been formulated, tested and documented by SEA-AR scientists. This model is valuable in helping to assess non-point pollution but does not specifically evaluate production-erosion relationships.

The 1980 CARD-RCA national modeling effort of English and Heady, (1980)*, included estimates of the effect of different rates of soil loss on average crop yields. These estimates are derived from an estimate of erosion for a given soil condition and land use system as calculated from the Universal Soil Loss Equation and estimates of yields by soil separations with various adjustments and trend assumptions. It is an elegant display of modeling technique, using enormous quantities of data. It is, however, limited in dependability by the accuracy of the yield estimates which rest on a very inadequate data base.

The Universal Soil Loss Equation (USLE) is in general use throughout the country to predict probable erosion losses. It is formulated in tables and graphs so that technicians, law enforcement officers, teachers and farmers have all necessary information to predict erosion under almost any conceivable land use situation.

The only readily available source of information of use to a wide audience concerning the effect of erosion on crop yields is the information that is presented in the county soil survey reports.

More detailed guidance is badly needed concerning the effect of changes in organic matter levels or of structure on productivity.

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* English, Burton G. and Heady, Earl O. Procedures used to determine yield productivity in 1980. CARD-RCA Modeling Effort. Paper presented at SEA-AR Conference in Washington, D. C. Feb. 1980)

AREAS OF CONFLICT

There is a general lack of understanding of the economic imperatives under which many farmers must operate.

The farmer is usually not willfully wasting a national resource when he permits his land to erode at a rate in excess of the defined desireable level. Within his planning horizon the 2 to 6 ton per acre limit on soil loss may appear to him to be unnecessary. On eroding lands, when productivity can largely be restored with fertilizer, his profits are in many instances maximized by maximizing grain production. In some situations most of the damage from erosion, at least over the near future, is off site. Also, in many cases, the surface is already eroded.

Many of the control techniques, currently available are, like terrace systems, costly and do not generate a commensurate amount of new income, or, are like forage based rotations, certain to result in a reduced income from the land.

A study by Rosenberry, et al, (1980), predicted the effects of soil depletion on farmer income.

In an economic study of the consequences of controlling erosion on cropland in a 5.3 million acre area in southern Iowa they found that the cost of reducing soil erosion to tolerable levels was three times as expensive as the benefits. They conclude that, "given this benefit-cost ratio, farmers will be hard pressed to finance erosion control without cost-sharing or similar public investment."

Making maximum use of minimum tillage practices to control erosion resulted in the least loss of income of any of the alternative systems examined. A system involving erosion control by a combination of terracing and sod-based rotations caused the greatest loss of income.

Most of the cropland soils in the southern Iowa region studied are formed on a loess or glacial till. These soils generally have a high capacity for holding water in a plant-available form. Some have medium textured subsoils but others have dense compact subsoils that are difficult to cultivate and on which erosion would cause a permanent disinvestment.

The Rosenberry, et al, (1980) study uses yield estimates from the Fenton, et al, (1971) production estimates for Iowa soils as a source of yield information and uses the Universal Soil Loss Equation to calculate erosion. Appreciable errors in these estimates are probable. However, in the unlikely case that an error of 100 percent might exist in the estimates, the conclusions based on 300 percent differences would still be valid.

It is futile to attempt to use educational programs to try to induce farmers to adopt practices that will control erosion if the farmer is certain that the required change will result in a marked reduction of his income. Continued high profits from cattle would be more effective in increasing grass acreage and thus reducing erosion than would any amount of urging from government officials.

Economists require accurate and dependable agronomic data if they are to produce valid studies. Agronomists and engineers, also, need to be fully aware of the economic implications of their recommendations. There is an urgent need for further research into erosion control practices that are both effective and profitable.

There is a need for critical consideration of the permissable soil loss or soil loss tolerance concept. The term, "soil loss tolerance" denotes the maximum level of soil erosion that will permit a high level of crop production to be sustained, economically and indefinitely. The range in permissable soil loss in use presently is narrow with most soils being in the 3 to 6-ton per acre per year range.

Because of data inadequacies, these estimates are probably too high on some soils and too low on others.

There is an almost total lack of critical information concerning desirable limits of tilth or soil structure parameters on different soils. Tilth is a problem on cultivated lands so this problem is of prime importance in the midwest, the region of cultivated land. Even though soils in this area appear to be quite resilient and tolerant of abuse, there is evidence that all soils have tolerance limits for structure and that a decline in structure below a certain, as yet undefined, level can be very costly for the nation.

Large areas have lost most or all of their surface soil. Erosion is continuing at a rate that will cause millions of acres of subsoils to be exposed in the next few decades. It is apparent that a considerable portion of our food and fiber will have to be produced on subsoils. Soil management problems peculiar to different types of subsoils have in some cases been identified, but little work has been done to learn the best procedures for maximizing production on subsoils.

To date, most of the small amount of work that exists on crop production problems on subsoils consists of comparisons of problems and production potentials on eroded and uneroded areas. It is time to accept the fact that erosion is occurring and will occur and to start an agressive program to learn how best to produce on a wide range of subsoils.

RISKS, COSTS OR FOREGONE PROFITS

When a soil is allowed to erode there is the risk that the productive capacity of the land may be permanently endangered. As stated in earlier sections of this report, this risk varies from slight to very severe. Lack of knowledge of how an individual soil will behave when eroded has led to both under-utilization and to catastrophic over-utilization and consequent destruction of the land as a productive unit.

There is, also, the risk that a farmer will sacrifice future productive capacity for present profit.

There has been a tendency among soil conservation technicians to accept and attempt to sell to the farmers, practices that will control erosion regardless of the effect of these practices on the farmers income. A greater emphasis in training of technicians in economic realities would help. Even more important is an active, agressive research program into systems that would both control erosion and increase income.

Better documentation than now exists of indirect effects of erosion on production, would also aid the farmer in making more rational decisions concerning land use than may now be the case.

Factors in this secondary category are such things as increased machine operating time and breakage because of rill erosion, difficulties of properly timing field operations because of uneven drying of eroded spots and uneven fertilizer needs in different parts of a field due to erosion differences. These result in either lower yields than necessary on eroded areas because of lack of fertilizers or a waste of money for unneeded fertilizers on uneroded areas.

Large areas are eroded. Land forming, terracing and dam construction expose subsoils. Increased attention to problems and potentials of crop production on subsoils would appear to be warranted.

SOCIETY AND EROSION

Society has a much longer planning horizon than does the individual farmer. A practice that will not reduce income to a farmer for the next 25 years is of little concern to many individuals but should be of great concern to the public as a whole. Interest in distribution of costs and benefits is also different for the public and the individual farmer. The public is affected by such offsite results of erosion as silted reservoirs, degraded fish habitats in streams or of increased frequency or severeity of flooding. The farmer who produces this silt may be less affected.

Society is also affected by anything that affects the cost of food. In the short run, food costs may be cheaper because corn or soybeans are produced on erosive land. If production on only non-erosive areas takes place, total volum~~s~~e of produce may be reduced and prices may rise. In such a situation, society as a whole is receiving a benefit from erosion. If, as is now the case, exports of grains are furnishing an important part of our foreign exchange, all society benefits from high production, even from that portion that is from eroding fields.

Society is benefitting from the use of the Universal Soil loss Equation because it furnishes a rational measure of erosion and can be used to identify situations where the public interest is in improved erosion control. The USLE is an essential part in state conservation laws. It is imperative that the USLE continue to incorporate the most modern data available and that a vigorous research program be continued to further improve the realiability of the estimates.

SUMMARY AND CONCLUSIONS

1. There are valid reasons for public concern about all off-site effects of erosion. The public stake in the effects of stream pollution, reservoir sedimentation, water

supply, contamination and like results of erosion are all legitimate reasons for public participation.

In many instances the reason erosion is occurring is that the costs of erosion control are greater than the benefits to the individual farmer. Public participation in helping with these costs appears to be reasonable.

2. There are soils so fragile that loss of even a few inches of topsoil through erosion results in a substantial loss of their productivity. It is in the public interest that such soils not be allowed to erode. At least some of these soils can now be identified and their location determined. Legislation is needed to prevent further deterioration of such lands.

   Large areas of rangeland, where the productive capacity is easily damaged by erosion, are public lands. Prompt action to halt further deterioration of these public lands would appear to be highly desirable and to be something that could be done quickly.

3. There are large groups of soils with subsoils favorable for plant growth on which the crop producing ability of these soils can be maintained by the use of fertilizers. On such soils the public does not need to be concerned with soil movement within a field. The public does have a valid concern for any soil that moves off of the field on a farm into streams, reservoirs, road ditches or onto neighboring farms.

A variety of types of structures, including terraces, detention basins and dams are available for holding the silt on the farm. Additional research in the area of construction of retaining structures is needed.

4. The productive capacities of most soils in the United States are reduced to some degree by erosion. An active research program into the degree of damage suffered and the causes of the damage is needed over a wide range of cropland soils as a basis for formulation of rational controls.

5. Large areas of soils of widely varying quality have lost most of their surface soils through erosion. Millions of additional acres will be eroded within the next few decades. A greatly expanded research program is needed to determine best use proceedures for these eroded areas.

6. Presently available farming systems that control erosion frequently result in a marked reduction in profit to the farmer as compared to systems that permit rapid erosion. Research into systems that have the joint objectives of increasing income and controlling erosion should be pursued.

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Background Paper No. 31

CHANGES IN THE CAPACITY OF CROPLANDS AND RANGELANDS TO SUSTAIN PRODUCTIVITY OF ENVIRONMENTAL SERVICES

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ABSTRACT

The effects of agricultural technologies on the productivity of environmental services from the land are reviewed for six general categories of agricultural practices most often identified with environmental quality. These are: tillage, seeding, fertilization, irrigation and drainage, pest management, and harvesting. Review of the data bases to evaluate mechanisms causing ecological changes and adequacy of these data bases are discussed. Recommendations for future research to consider holistic agricultural ecosystem level approaches are stressed. Modification of governmental policies are identified to promote increased production of environmental services of agricultural lands.

INTRODUCTION

Today's American farmer is confronted by a series of challenges to his profession. Land resources are being lost to erosion and non-agricultural interests. Inflation and rising energy costs have placed an additional burden on the farming operation. In addition, the nation's growing environmental awareness is expressed in new legislation, outlooks, and values. Agricultural technology designed to increase farm productivity and profit is changing rapidly. The intensification of this change in the farming operation will affect the capacity of croplands and rangelands to maintain an acceptable level of environmental quality. Juxtaposing of agriculture and environmental services indicates the need for a holistic ecosystem level approach to the problem.

An ecosystem may be defined as a system with relatively discrete boundaries containing both biotic and abiotic components and having flows of energy through it and cycles of nutrients within it. Agricultural ecosystems (agro-ecosystems) also fit within this definition. It is important to note though that the boundaries of an agro-ecosystem are not the edge of a crop field. An agro-ecosystem at least includes adjacent crop fields, neighboring uncultivated areas, and aquatic systems within the same watershed. An agro-ecosystem includes all the community types with large flows of energy, materials, or information between them. These considerations could lead to the view that agro-ecosystems are quite large units, with the earth being one large ecosystem. This view may in fact be appropriate if an environmental problem is global in extent. Some other agricultural activities, such as tillage practices, involve individual watersheds or drainage systems.

The agro-ecosystem concept has been developed to demonstrate the futility of treating agricultural problems as if each farm field were a separate, totally isolated, non-interacting entity. Experience with insect pest management using pesticides alone has demonstrated that agriculture is intermeshed within a much larger system of interactions. Nearby uncultivated areas act as sources of resistant and secondary pests as well as sources of predators and parasites of those pests. Currently, insect pest managers monitor the insect activities in uncultivated areas as diligently as they do in the adjacent farm fields. They have learned the futility of considering the crop field in isolation from the rest of the system.

The approach in writing this paper was to define (implicitly) an agro-ecosystem in the context of the problem being considered. It is believed that this is the appropriate manner in which to investigate the effects of agricultural technologies on the productivity of environmental services from the land.

In the design of this paper, five services of natural ecosystems were identified. They are: production of clean air and water; maintenance of healthy, fertile soils; provision of wildlife habitat; and continued long-term agricultural production. Next six general categories of agricultural practices were identified that affect the land. These are: tillage, seeding, fertilization, irrigation and drainage, pest management, and harvesting.

This paper is designed to assess the data base available within each block. Rates at which changes in environmental services from agricultural lands are occurring are reviewed. Hypotheses are outlined and evaluated on the mechanisms causing ecological changes from changing technology. In addition, the adequacy and compatibility of the data is discussed. Special attention was paid to irrigation and drainage, tillage, and pest management. Brief general comments were made concerning harvesting, seeding, and fertilization. Government policies which result from inadequate understanding of ecological impacts on agro-ecosystems resulting from agricultural technologies are discussed in light of risks to farmers and society in the conclusion section. Finally, recommendations for further research to describe the range and degree of changes in the capacity of croplands to provide (or maintain) environmental services are listed.

AGRICULTURAL PRACTICES

Tillage

Residue management is a developing agricultural technology which either maximizes plant residue levels on the surface of tilled soils (i.e., conservation tillage, no-tillage, double cropping, mulching) or minimizes surface residues by harvesting all plant produced biomass (i.e, energy production). These two techniques are compared in this section as to the degree they affect air, soil, and water quality of the agricultural and surrounding environments.

Most segments of the agricultural research community have or are developing research projects on residue management in farming operations. Research on maximizing surface residues (conservation tillage) to increase productivity began in the late '60s by the United States Department of Agriculture - Science and Education Administration (USDA-SEA) and state experiment stations. The technique was not widely applied until the mid '70s. In 1974 the U.S. Department of Agriculture estimated that the amount of cropland in the United States under conservation tillage was 2.23 million hectares (of a total cropped area of 140 million hectares) and that 62 million hectares or 45 percent of the total U.S. cropland would be under conservation tillage by 2000 and 78 percent by the year 2010 (United States Department of Agriculture, 1975).

Each geographic region in the United States has a group of researchers active in conventional tillage research tailored for their given area. Generally these are USDA-SEA and university experiment station personnel. Soil Conservation Service (SCS) has played a dominant role in the transfer of this technological information into field operations. Environmental Protection Agency (EPA) has provided some funding for erosion studies and modeling activities to predict how employment of various technologies will maintain environmental services of the land. The National Science Foundation (NSF) has recently funded investigations in two geographic regions (Coastal Plain and Great Plains) to assess agricultural technology and environmental quality.

The Soil Conservation Service reports a 320 percent increase in the number of cropped acreage not plowed between 1969 and 1975

(Griffith et al., 1977) in the Eastern Corn Belt. Generally all aspects of environmental services brought about by this shift in tillage practices have been considered by area researchers. Consideration has been given to erosion losses, water conservation, yields, fertilizer timing and amounts, changes in soil characteristics, weed and insect control, and special attention has been given to soil erosion by wind.

Fall shredding, cropping, or disking residue followed by mall board plowing is the primary tillage technique used in the Western Corn Belt (Amemiya, 1977). Secondary tillage employing harrows or cultivators follows in the spring. As recently as 1976 only one-third of Iowa's total row crop acerage was conservation tilled.

In the Northeast, conservation tillage practices have been applied to corn, soybean, and horticultural crops as well as pasture renovation. Environmental consideration has generally been limited to temperature and moisture relations (Bennett, 1977). In West Virginia, corn planted in grass sod modified soil temperatures as much as 10°C compared with conventional tillage. Soil moisture in the Northeast usually is sufficient for normal planting growth under reduced tillage whereas plants grown under conventional tillage often suffer severe moisture stress. With conventional tillage most available soil moisture is lost in seedbed preparation.

The Southeast has been projected to benefit more from conservation tillage than any other region of the United States (Reicosky et al., 1977), because of the climatic factors which make possible a double cropping management alternative. Availability of precipitation (and groundwater for irrigation), long growing season, and land availability has stimulated an interest in conservation tillage practices to parallel the increase in agricultural production within the area. No-till production on corn and soybeans has been widely accepted throughout the Southeast (Reicosky et al., 1977; Phillips et al., 1980). Factors considered in research on conservation tillage in the Southeast have included infiltration and storage of soil water, changes in physical properties of soils, erosion losses, fertilization, insect and weed control, and economics.

In spite of the lack of interest by farmers to adapt conservation tillage practices in the Western Corn Belt, research by USDA and university scientists has demonstrated the role of tillage generally and plant residues specifically in controlling soil and water losses (Amemiya, 1977).

In the semi-arid Northern Great Plains stubble-mulching is the more popular tillage practice (Fenster, 1977). Advantages of stubble-mulch farming are the creation of soil conditions which are resistant to erosion, protection of the soil surface from wind and water erosion by employing a vegetation cover, and conserving moisture. Investigation on stubble-mulch research is underway at most experiment stations in the Great Plains.

Wind and water erosion are dominant environmental problems in the Southern Great Plains. Unger et al. (1977) indicate conservation cropping systems (conservation tillage and residue management) are used on only 11 percent of the cultivated cropland in this region where soil erosion is a major problem. Poor weed control and planting problems in heavy residues have been attributed to the farmer's lack of acceptance of minimum or no-tillage techniques. However, sufficient technology information has been forthcoming from USDA-SEA and experiment stations within the region.

Despite years of research and development by USDA and experiment stations on tillage and cropping practices in the Pacific Northwest, efficient water use and soil protection goals have not been achieved by area farmers (Papendick and Miller, 1977). Wind and water erosion remain major problems especially in dry land farming areas. Systems in use or under study include stubble mulching, fall chiseling, and minimum tillage. Farmers have been reluctant to accept these techniques because of reported depressed crop yields. Yield increases with plowing could be a response of nitrogen mineralization rates being greater in the bare, warmer soil.

The potential for multi-cropping may be the single most important factor in no-tillage agriculture. With the no-tillage system, harvesting can be followed by planting of a succeeding crop such as small grain, corn, soybeans, grain sorghum, sunflower, flax, and others. The greater potential for double cropping is in the southern regions which provide a longer growing season. Conservation tillage studies indicate that soil erosion can be reduced to almost zero. Nationwide 42 percent of the cropland has no conservation tillage and contributes 57 percent of all sheet and rill erosion (Davis, 1977). The presence of surface residues increase infiltration of rain and irrigation water resulting in significantly more water for plant growth and reducing the need for irrigation. Conservation tillage requires less energy and machinery costs than conventional tillage. This is due to reduced energy and machinery requirements for plowing and fewer trips for cultivation. Reduced traffic lessens compaction of the soil. Conservation tillage requires less labor but greater management ability is required for success.

Conservation tillage offers greater flexibility in land use. Conventional tillage on steep and marginal land might create severe erosion problems if these areas were cultivated. In general, crop yields reported for conservation tillage are as high or higher than those obtained with traditional tillage practices (Phillips et al. 1980).

A disadvantage for conservation tillage is higher chemical costs resulting from increased usage. Some of the energy saving of conservation tillage may be offset by increased pesticide usage and its energy requirements for manufacture. Since no cultivation is involved, herbicide rates are often two and a half times as high as under conventional cultivation (Davis, 1977). This increased usage might result in the possibility of residual pesticide buildup in the soil which might damage subsequent crops, result in damage to beneficial soil fauna and flora (birds, field mice, insects, and microbial populations) and an increse in resistant weed species.

Renewed interest in energy production from agricultural products indicates the need for a series of assessments on residue removal and environmental quality.

The overall effect of nutrients removed from the field in harvested residues is not well known. Increased fertilizer usage may be necessary to continue to maintain soil productivity in fields from which the residue was removed. For example, Franzen and Welch (1978) calculated that harvesting non-grain corn residue in Illinois removed about 56 kilograms more nitrogen/hectacre than would grain harvest alone. For phosphorus, 3 kilograms were removed by non-grain residue harvest. Eighty percent of the total potassium was in the non-grain portions and its removal would require replenishment by fertilizer for future crop production. Jones (1976) noted that complete residue removal from Nigerian millet-maize rotations results in a decline of soil exchangeable K and Mg by a respective factor of 44 and 12 percent.

In the Southeast, estimated loss of nutrients in residues from continuous soybean plus nutrients lost via erosion would range from 62 to 83 kilograms/hectare for N and 19 to 31 for P (Larson, 1979; Holt, 1979). Similarly, a wheat-pea system in Oregon would have a loss of 100 kilograms/hectare of N and 18 of P.

Crop residues are also an effective soil erosion control device for wind mediated losses (Skidmore et al., 1979). Holt (1979) concludes that removal of crop residues will increase wind erosion and its associated nutrient losses for N and P will exceed that for residue production in four of five major land resource areas.

Estimates have been made for the amounts of residue that can safely be removed (without excessive soil erosion) in major land resource areas by using a model based upon the Universal Soil Loss and wind erosion equations for current cropping practices. Application of this technique has been to the Great Plains (Gupta et al., 1979) Corn Belt (Linstrom et al., 1979a 1979b), and to the Southeast (Campbell et al., 1979) regions of the United States. The highest amount of available residues in the Southeast are located in the southern Coastal Plain and Atlantic Flatwoods area of Georgia and North and South Carolina. Campbell et al. (1979) estimate about 4.0 million metric tons of residue could be available from designated areas in these states without exceeding tolerable soil loss limits. However, in using these models, no attempts were made at predicting long-term effects on soil productivity associated with residue removal.

If residue management for energy production is to increase, improved harvesting and fermentation techniques need to be developed. Buchele (1976) reviewed current technology to remove surplus crop residues for feeding brood cows, heating farm buildings, drying grain, and for off-farm energy generation. He further explained the need for development of conservation tillage equipment to provide maximum production of plant residue on the soil surface. Reichenberger (1979) compares the harvesting of corn, soybean, and wheat residues using round balers, flail-equipped stackers, standard-forage choppers, and a combine-towed-field-dump wagon; the latter being the cheapest harvesting method, provided it does not interfere with harvest operations.

Proper use of crop residues may be the best means to control wind and water erosion while maintaining the quantity and quality of water running off agricultural lands (Larson, 1979). Aarstad and Miller (1973) demonstrated that the presence of plant residues reduced runoff from sugarbeet and potatoes when irrigated by center pivot sprinklers. They point out that the use of plant residue is not practical unless the material was grown in place. In an earlier study (Miller and

Aarstad, 1971), wheat straw incorporated into the soil surface increased infiltration and reduced soil erosion within the irrigation furrow. Similar results were shown for corn residue (Aarstad and Miller, 1978). Wischmeier (1973) calculated that each 2.2 metric ton of residue per hectare on the soil surface reduced soil loss from water erosion by 65 percent.

Onstad and Otterby (1979) used available data in conjunction with a recently developed SEA residue management model to predict mean annual runoff from four hydrologic soil groups. Crop residue on the surface decreased runoff from all storm sizes. Runoff reduction and subsequent increase in soil water storage was greatest in the Southeastern United States.

Estimates of energy production from solar biomass range from 25 percent of current U.S. energy needs if all biomass, including grains now used for human or animal feeds, is used (Burwell, 1978), to 10 percent if innovative production techniques such as double-cropping are employed (Lipinsky, 1978), to 1-2 percent given current cropping practices (Larson, 1979). Even with complete removal under current cropping practices, the energy production resulting could only account for twice the energy used today in agriculture. Residue conversion into an energy product may have an impact on agricultural energy usage, however, other industrial applications may be limited due to processing, transportation, and storage costs. Koelsch et al. (1977) calculated wheat straw would not economically compete with coal as a fuel source for a municipal electrical utility in Pratt, Kansas.

Seeding

Changes in environmental services related to seeds and seeding are generally related to the development of new strains which confer increased resistance to weather, salt, diseases, insects or nematodes, or increase production efficiency.

The possibility for decreased use of insecticides and nematicides due to greater plant resistance would cause an increase in environmental services since decreased transport of pesticides would likely result. Increases in weather resistance would probably result in a net decrease in environmental services since crops could be grown for longer time periods requiring extra fertilizer, tillage, and pesticides and decreasing or eliminating annual fallow periods. Alternatively, drought resistance would decrease the need for irrigation.

Enhanced salt resistance would allow extension of cropping into areas that are naturally too saline or which have become too saline due to irrigation practices. Irrigation return flow from these areas is likely to be more saline.

Even though new varieties of the major crops are frequently developed, we find ourselves with extreme genetic uniformity in large percentages of the acreage devoted to this crop. For example, three varieties of snapbeans and two varieties of peas make up 76 percent and 96 percent, respectively, of the acreage devoted to these crops. The key lesson of the corn blight in 1970 is that genetic uniformity is the basis of vulnerability to epidemics (National Academy of Science 1972). The loss of genetic resources useful to agriculture can be seen as a mechanism by which the long-term productivity would be adversely affected.

Fertilizer

Billions of tons of nitrogen fertilizer are applied to agricultural crops on a worldwide basis each year. In addition, range management practices call for the use of fertilizer to increase forage production. Any nitrogen in the soil not taken up by the plant may undergo microbial conversion and either enter the atmosphere (denitrification) as a gaseous product, become part of the soil structure (bound on clays or transformed into humus), or appear as nitrate in ground or surface waters. One explanation for the increase of nitrate levels in ground and surface waters draining agricultural lands is fertilizer application (Singh and Sekhan, 1979). Control of nitrate pollution of natural water from agriculture may be possible by construction of water level control structures in tile drains and outlet ditches to increase denitrification in the field (Gillam et al., 1979). Other approaches are to match application rates of fertilizer nitrogen to the uptake rates of the plants (Singh et al., 1978). It has also been hypothesized that natural riparian vegetation in the eastern United States can be very important in keeping NO_3-N from fields out of the surface drainage (Wharton, 1978).

Data from irrigated fertilizer crops indicate a potential risk of nitrate pollution of ground water (Bauder and Schneider, 1979). The practice of fertilizer application mixed with irrigation water is becoming more attractive as a management tool as energy costs increase. Certainly fertilizer (and/or waste) application with irrigation water and resulting contamination of surface and ground water (to say nothing of aerial drift) could become a paramount environmental problem for agriculture.

Research on the effects of fertilizer application (type, timing, and levels) on environmental services of agricultural lands is needed. Too little data is available on waste application to land and its overall impact on the environment. As agricultural technology advances, fertilizer management must be considered as an impact on soil, air, and water quality.

Irrigation and Drainage

The components of the agricultural environment most affected by irrigation and drainage are water and soil. Data gathered on surface water quality and quantity falls into two broad categories: routine monitoring and special research projects. Governmental agencies involved in long-term monitoring include the USDA-SEA, United States Geological Survey (USGS), EPA, and various state water quality agencies. The Water and Power Resources Service (formerly Bureau of Reclamation) gathers data on irrigation return flow at their project sites in the western United States. These data are pertinent to agricultural land use if they are being taken in areas where water quality is influenced by agriculture. Except for USDA activities, these measurements are not being done to assess the impact of agriculture on water quality but are part of a more general monitoring program. In other words, most water quality data indicates ambient water conditions and are not indicators of causal relationships.

Water quality data is often gathered in specific localities by academic researchers as a means of answering particular questions. Research projects which relate water quality to land use are in their infancy and usually involve looking at broad land use categories and their effect on water quality (Kuenzler et al., 1977).

Data on changes in soil properties related to agriculture fall into the same two broad categories: long-term routine monitoring and problem oriented research. The Soil Conservation Service is engaged in an ongoing process of completing and revising soil surveys in various parts of the country. Changes in soil taxonomy and classification require changes in soil survey maps. These data are generally useful only in identifying long-term changes in soil properties which might be causally linked to agricultural practices. Research on specific systems of irrigation and drainage as they affect soils are carried out by the USDA-SEA, state experiment stations, and university research groups.

Data on quality and quantity of ground water is collected primarily by the USGS and the USDA-SEA groups in special research projects. The Water and Power Resources Service does monitoring of ground water quality at their development projects.

The USDA has carried out hydrologic research since the late 1920s starting first with SCS projects which were subsequently transferred to the Agricultural Research Service (now Science and Education Administration). There are watershed research centers located around the country at Burlington, Vermont; University Park, Pennsylvania; Tifton, Georgia; Boise, Idaho; Chichasha, Oklahoma; Columbia, Missouri; Coshocton, Ohio; Temple, Texas; and Tucson, Arizona. These centers operate a total of over 240 instrumented watersheds ranging in size from a few hectares to 12,300 square kilometers. These centers originally collected data on just stream flow and precipitation but in the last 10 years have begun to collect data on water quality also. The streamflow and precipitation quantities are obtained in sufficient detail for breakpoint processing, often at five minute intervals (Burford, 1977). Water quality data from these centers is compiled into a central data bank at the Hydrologic Data Laboratory in Beltsville, Maryland.

The USGS collects water quality and quantity data at approximately 140,000 surface water sites and 420,000 ground water sites. These data, mostly related to water quantity, are accessible through the National Water Data Storage and Retrieval System (WATSTORE).

Water quality data are compiled in an EPA run system known as STORET. This data base keeps track of water quality data from any site in the United States, for any purpose, for any state or federal agencies. Altogether approximately 60 million data observations for 400,000--600,000 sites are stored. Currently 42 states are involved in this service through state water quality agencies. The three largest users of the system are the USGS, United States Forest Service (USFS), and the Army Corps of Engineers. The agriculture sections of USDA are not tied into this data storage system although agriculture is included as a site type in the classification scheme.

These data bases indicate that there are likely to be water quality and quantity data available on most agricultural watersheds or on a nearby watershed. The adequacy of the frequency of collection and type of data collected would depend on the specific use of the information.

Water quality parameters of most interest in croplands are primarily chemical constituents. The chemical makeup of water relevant to agricultural practices would include the plant nutrients and pesticides applied to croplands. Due to the dilution factors associated with stream flow, many chemical constituents are near detection limits for the analysis techniques used. Common nutrient species of interest in runoff are nitrate, phosphate, chloride, calcium, magnesium, potassium, and sulfate. In irrigated lands, the primary chemical indicator of water quality is the total salinity in irrigation return flow. The total salinity is the total quantity of dissolved solids present in water (Carter, 1975). Groundwater quality is generally indicated by the same parameters as used for surface water. Once again changes in salinity are of primary concern in groundwater under irrigated croplands.

In order to calculate actual quantities of dissolved or suspended material in water, both the quantities of water and the concentrations of the material of interest should be known or estimable. In general, for surface flow, estimation of flow quantities past a point is done by correlating a readily measured parameter such as depth or height of water with a record of quantity of flow to obtain a rating equation. Flow quantities can then be predicted from gage height measurements. Most methods of streamflow prediction/measurement are strictly empirical.

Estimation of quantity of groundwater flow is generally less empirical, more difficult, and more fraught with errors. Groundwater flow can take place in confined, unconfined, or partially unconfined geologic material. The material can have porosities and permeabilities that change independently of each other in both time and space. Flow gradients may or may not be related to land surface gradients. In other words estimation of groundwater flow of an actual drainage basin of any appreciable size can have very large errors associated with it. This is why in most studies of the effect of agricultural practices on groundwater, reference is made to chemical concentrations in the groundwater and not actual chemical loads.

The effect of irrigation and drainage on soil properties can be a long-term process involving oxidation or accumulation of soil organic matter, salt accumulation or depletion, changes in exchange capacity, and changes in soil structure. The effects can also be important over the course of one growing season or portion of the season due to practices such as drainage control (Gilliam et al., 1979). Soil survey material which describes primarily physical soil properties can be useful in assessing long-term changes in the soil system. In general, in order to correlate changes in agricultural practices with both changes in soil and water properties, the same measurements of chemical constituents should be made in both systems. For instance, if the segregation of nitrogen fertilizer into plant, soil, and water components of the agricultural system is of interest, then nitrate, ammonium, and total nitrogen should be measured in both soil and water (Gerwing and Caldwell 1979). Measurement of changes in soil chemical properties are generally made monthly at most, and in croplands often only spring and fall measurements are considered important.

Research into the effects of agriculture on water quality has been guided to a large extent by legislative mandate contained in section 208 of Public Law 92-500, the Federal Water Pollution Control

Act, passed in 1972. This law stated as a goal the elimination of discharge of pollutants to the nation's waterways by 1985. Agricultural practices including irrigation and drainage, (as well as fertilization and pesticide application) are implicated in the production of non-point source pollution due to surface and subsurface movement of dissolved and suspended materials from croplands into the nation's waterways. Klingeman (1976) estimates that more than half of the pollutant load in the Columbia River Basin is from non-point sources. It is perhaps impossible to estimate the proportion of this which is contributed by agriculture.

The increase in research effort related to non-point source pollution was dramatic in the five year period from 1974 to 1979. The Journal of the Water Pollution Control Federation referenced no sources in their 1974 annual literature review issue, whereas in 1979 at least 30 references related specifically to agricultural non-point sources.

Soil and water salinity is a problem on about one-half of the irrigated land in the United States. Crop production is limited by excess salinity on about one-fourth of this area or about one-eighth of the total irrigated cropland. Excessive salt accumulations occur primarily because of the consumptive use of water by irrigation. The decrease in water quantity due to evapotranspiration increases salt concentrations in the remaining soil water and in the runoff water (Carter, 1975). Reeve and Fireman (1968) point out the need to know the salt balance and leaching requirement (i.e., excess water needed to remove salt accumulations) on a site-specific basis. Miller et al. (1978) includes biological oxygen demand and phosphorus as the primary pollutants in irrigation return flow. El-Ashry (1980) designates soil salinity and salinity in groundwater supplies as two major problems facing irrigated agriculture. These studies point out a great gap that must be bridged between pollution monitoring and pollution control and the impact on environmental services. Impacts on biotic components of the ecosystem are seldom considered as the output of these environmental pollutants.

Irrigation has the capability to affect the input environment, i.e., the water supply as well as the agricultural system (croplands) and the output environment, i.e., disposal areas for leachate and return flow. Large scale withdrawals of groundwater in the southern Great Valley of California has caused subsidence of over 3 meters over relatively large areas (Poland and Davis, 1956).

Irrigation with wastewater effluent is receiving much needed research attention. Many factors have been shown to affect the quantities of nutrient (especially nitrate) leaching including rate of application, time of application, and nutrient concentrations in wastewater.

According to the SCS drainage handbook about 53 million hectares are drained artifically (Soil Conservation Service, 1973). This is about one-third of all cropland in the United States. Drainage methods in areas east of the Mississippi River generally employ drain tubes placed about 1 meter below the surface to lower the water table. On irrigated land in the West, drain tubes are placed 2.5-3 meters deep to reclaim saline and alkaline soils and prevent waterlogging. Thus on irrigated land, drainage systems can contribute to pollution of return flow while decreasing soil salinity.

Artifical drainage of croplands tends to deliver loads of pollutants, especially nitrate, more quickly than natural drainage. Vithayathil et al. (1979) report an average of 12 studies shows 17.6 kg/ha of NO_3-N lost from artificially drained land. Data from North Carolina show that poorly drained soils with high water tables lose less NO_3-N to drainage waters than do well drained soils because of denitrification in the subsoil of the poorly drained soil (Gambrell et al., 1975). Drainage control might be used to diminish nitrate losses by enhancing denitrification and decreasing the volume of drainage.

The focus of much research on agricultural pollutants is nitrate movement in natural and artificial drainage in surface and subsurface water discharge. The United States Public Health Service has long recognized the hazards of nitrate pollution and has set the upper limit at 10.23 ppm NO_3-N in water. It is quite unlikely that the major surface drainage of agricultural watersheds will exceed this standard although tile drains from individual fields can exceed it by three to five times.

Thomas and Crutchfield (1974) were able to find no relationship between land use and nitrate loss. Agricultural watersheds did not show higher NO_3-N concentrations than watersheds with forested or urban land uses. This study points out the need to be able to measure nutrient loads and to consider other forms of the same element.

The above discussion lists many of the ideas which researchers have on the extent and magnitude of the interface between croplands and water quality. Actual hypotheses about the mechanisms by which agricultural pollutants from irrigation, fertilization, and drainage affect the productivity of environmental services are indeed sparse. The effects of cultural eutrophication were among the first to be identified by a pollution-conscious society, but agricultural practices generally contribute only a small amount to these problems. Changes in surface water salinity can obviously affect the downstream biota and increase the incidence of halophytic vegetation such as salt cedar (*Tamarix gallica*) which is considered a pest in dry western areas due to its large water use through evapotranspiration. The lack of information on specific effects of these pollutant outputs indicates a large gap in the hypothesis and research process which should be evaluating the effects.

As noted above, artificial drainage in the United States can be divided into two kinds of systems being utilized for two different purposes. The same is true of irrigation. In the West, irrigation is generally carried out in order to make it possible to grow crops in a particular area. In the East, irrigation is generally used to supplement rainfall in dry years or during drier portions of the growing season which are crucial to crop development. Since irrigated agriculture is fairly new to the East, most of the data collected has come from the large irrigation projects in the West. Much of the large body of scientific literature that already exists on irrigation is "discipline bound" and does not take into account the complex interactions between the various ecological components of the system (White, 1978). White sees this as primarily a problem born from the type of research funding generally offered: "when funds are allocated for research or irrigation, drainage and associated problems, the tendency is to use the customary channels of government agencies and university departments. These generally are organized along disciplinary lines which are established, convenient, and effective in terms of research methodology. They nevertheless encourage work which fails to perceive or explore the gaps between disciplines or to take adequate account of the linkages among sectors of acute problems inherent in irrigation and drainage."

After an evaluation of models of irrigation return flow, Walker (1978) concluded that in most cases adequate field data were not available for input to the models and that non-research personnel need a usable model of return flow from large scale agriculture.

Irrigation is perhaps the agricultural practice which would be first to fall under serious economic scrutiny, especially when public monies are involved. In 1978, reports appeared which attempted to assess socio-economic and technical considerations involved in reducing pollutants in irrigation return flow (Vlachos et al., 1978; Evans et al., 1978). The studies concluded that $750,000 of control yields $2,000,000 worth of benefits.

Even though the census of agricultural drainage has been taken every 10 years since 1920, problems of non-uniformity in data reporting and collecting make it difficult to assess changes in the amount and types of drained lands. Without an adequate data base on extent of drainage, it will be difficult to develop national policies on drainage. Since in large parts of the country artificially drained lands are responsible for high concentrations of plant nutrients entering waterways, much attention has been devoted to modeling and predicting runoff from tiled fields.

As noted above, USDA water quality data is not tied into the STORET system. Nor is there a consolidated data base for information pertaining to drainage and irrigation. Development of this sort of record keeping system would surely enhance the integration of research activities in these areas.

As a means of reaching the goal of zero discharge by 1985, section 208 of the Federal Water Pollution Control Act created a cooperative local/state/federal system for area-wide water quality planners. Each state made an assessment of the actual or potential impact of agriculture on water quality as non-point sources. Any actual "208 planning" is challenged by the need to locate, interpret, and compile past findings into forms useful for section 208 planners (Sweeten and Reddell, 1978). The pursuit of solutions to non-point source pollution problems on a state-by-state basis perhaps is an attempt to ignore the fundamental units of study generally favored by ecologists and environmental managers--the river basin or watershed.

Identifying, controlling, and evaluating the management of non-point source pollutants will probably prove to be an impossible task on a very large scale. Haith (1974) found regression models unsuitable for predictive purposes in investigations of the relationships between land use parameters, physical watershed characteristics, and water quality.

Sediment loss is one of the primary means by which non-point source pollution takes place. The Universal Soil Loss Equation (USLE) (Wischneier and Smith, 1960) and the Modified Universal Soil Loss Equation (MUSLE) are used to estimate soil loss from rill and sheet erosion on watersheds. Kuh and Reddell (1977) propose a two-dimensional erosion model which predicts both total quantity of erosion and the distribution of erosion and sedimentation on a watershed. Most modeling of non-point source nutrient movement from watersheds assumes the association of nutrients with sediment (McElroy et al., 1976) although in the case of nitrate, leaching and subsequent drainage to streamflow are likely more important processes.

It seems likely that hydrologic transport models will be widely used in the future (Larson, 1973). In these models, chemical movement is tied to the transport of water. In certain geographic areas, the use of these models brings up an interesting contradiction: the models as well as field observations tell us that nutrients are moving from the fields, but in many parts of the humid East actual watersheds devoted primarily to row crops cannot be shown to have higher nutrient concentrations in streamflow than forested or pastured watersheds (Thomas and Crutchfield, 1974). This points out the need for evaluating the role of natural riparian vegetation and other less managed portions of the agricultural ecosystem in maintaining water quality.

Once policies for control of non-point source pollutants are suggested, a serious and rigorous evaluation of both effectiveness of control and cost effectiveness is needed. Wade and Heady (1978) used a national agricultural model to test hypothetical policies of sediment control. Their minimum sediment alternative had costs that greatly exceeded benefits although actual values for many non-market goods are difficult to determine.

Pest Management

Practitioners of Integrated Pest Management (IPM) are proud of having reduced environmental impacts with their strategies that involve a minimum of pesticide application. However, even with good integrated pest control programs, the demand for pesticides will probably continue to grow (Smith and Reynolds, 1972). However, it should be noted that IPM affects all phases of agricultural production--planting and harvest dates, tillage practices, fertilization schemes, irrigation, crop diversity, plant spacing, etc. Environmental impacts due to these practices as influenced by pest management decisions should be considered, especially for crops such as cotton, where pest management is the ultimate concern.

In a sense then, IPM is both very narrow and very broad in its conception of pest problems. It has made great strides forward using the ecosystem prespective to solve pest problems. However, by focusing in so narrowly on pest problems, it has failed to consider the impact of its solutions on the whole ecosystem, that is, on nutrient cycling, water quality, etc. In addition, pest management, either by pesticides or other techniques, has not come up with a suitable method for assessing the environmental or economic cost of controlling a "pest" population that certainly is beneficial to some extent (certain life stages may function as pollinators, herbivory may favorably affect nutrient cycling).

A survey of the 1979 pesticide literature indicated that the largest component (25 percent) was the result of university research. This could be deceiving in that government research may be generating results that are being used within an agency without being published. Likewise, private industry is generating results that are not published in the open literature.

Most research involved the physical behavior (leaching, run-off characteristics, volatilization), metabolism or degradation in soil or water, or residues in soils or organisms. The pesticide research is very unsystematic, with the exception of residues noted below. For example, studies of pesticide degradation, one of the weakest spots in our understanding of pesticides in the environment (Kaufman, 1974), seem to be initiated without regard for the contribution that could be made to the synthesis of existing knowledge. Choice of pesticide for study, length of the study, environmental conditions, and other factors appear to be dictated by convenience.

Some systematic work is being reported with regards to the physical behavior of pesticides. In fact, most of the truly experimental, as opposed to descriptive, work has been performed in this area.

There is an overwhelming literature available on residues in animals, soils, plants, and waters. In particular, in the United States, since the establishment of the National Pesticide Monitoring Program in 1964, certain monitoring activities have become systematized. The program monitors pesticide residues in a variety of organisms and soils from specific sites across the United States at specific times. A summary of one of the programs can be found in Nickerson and Barbehenn (1975). Results of the program are reported in the Pesticide Monitoring Journal.

Although United States residue work may be adequate, it is not in other areas, particularly in South America, Asia, and Africa (Edwards, 1973). This is of concern to our pesticide control activities in that our migratory species may be acquiring a pesticide burden from outside the United States. For example, Risebrough (1978) believes that the continued reproductive decline of peregrine falcons is due to their encountering DDT in South America.

The considerations discussed above are tangentially related to the question of determining rates at which environmental services from agricultural land are occurring. They indicate the rate at which a disservice, propagation of pesticides throughout the environment, is or has occurred. The effect of this on specific organisms is the subject of some research and is relevant to the appraisal of environmental services from the land. However, the actual problem of changes in environmental services from agricultural lands due to pesticide applications has not been addressed. The consequences of pesticide movement through the environment and the effects that produces has been monitored. The effect pesticide application has on the ability of agro-ecosystems to provide clean water, provide a site for gas exchange, recycle nutrients, and maintain primary productivity has not been studied. The need for holistic, ecosystem-level experimental studies involving pesticide perturbations to agricultural watersheds is indicated.

The best documented effect of pesticide usage has been the direct toxicity to numerous animal species in both terrestrial and aquatic systems (Duke, 1977). Newsome (1972) relates some of the wildlife problems that resulted from agricultural pesticide application in Louisiana. The decline of fish-eating birds due to egg-shell thinning and its correlation with pesticide residues has been a dramatic and well-documented example (Hickey and Anderson, 1968; Anderson and Hickey 1972). Laboratory studies have substantiated the toxicity of pesticides to non-target organisms. In fact, laboratory studies probably underestimate toxicity since lab animals are not exposed to natural stressing agents that can act synergistically with pesticides.

The direct toxicity of certain pesticides to bees (Newsome, 1972) can affect both agricultural productivity and environmental services. Long-term decreases in primary productivity as a result of inadequate pollination is a possibility that deserves attention.

An interesting and ironic aspect of insecticides is that they have resulted in the generation of secondary pest species and pest resurgences due to their adverse effect on predators and parasites (Gillham, 1972). This indicates the potential for food web instability caused by pesticides. The repercussions that will be generated throughout entire ecosystems due to food web instability are unknown. Lack of knowledge of food web interactions is reflected by pesticide usage decisions. Use of endrin in Louisiana was limited after years of massive fish kills. It was replaced by zinphosmethyl, which is not nearly as toxic to fish, but is much more toxic to two species of cladocerans that the fish feed on. The outcome of this change has not been monitored (Newsome, 1972).

A major impact of pesticides has been indirect. Pesticides allowed the development of large monocultures with concomitant wildlife habitat destruction (Risebrough, 1978). Whether this trend will be reversed as integrated pest management programs are initiated remains to be seen. A mosaic of habitats is necessary for biological control of pests to provide cover and alternate food sources for a variety of life stages of predators and parasites (Price and Waldbauer, 1975)

Despite Malone's (1969) research indicating that insecticides can affect plant species diversity and productivity, experiments with plants have been limited to uptake experiments mainly for the purpose of assuring that pesticide residues in crops remain low. The long-term effect of pesticides on plant production should be an area of concern.

The direct impact of pesticides on aquatic systems is apparent and need not be stressed here. It should be noted though that pesticides can be applied so as to minimize the amount reaching waterways. (Baker and Johnson, 1979). For example, incorporation of herbicides into soils resulted in less runoff than does surface application (Baker and Laflen, 1979). Ultra-low volume or small drop application of insecticides decreases the total amount of pesticide in the environment. Pesticide usage can indirectly enhance water quality from agricultural fields. Conservation tilled systems, dependent upon herbicides for removing competition, are subject to considerable less soil erosion and nutrient loss than conventional tilled systems (Phillips et al., 1980).

The possibility that water quality has been affected by disruption of soil nutrient cycles by pesticides has not been suggested and is in need of investigation. Numerous studies have shown that of the microbial processes in soil, nitrification and legume nodulation are especially sensitive to various pesticides (see reviews of Parr, 1974 and Anderson, 1978). Decreased nitrification rates can be advantageous since leaching losses of nitrogen are decreased. However, decreased nitrification may result in enough soil ammonia accumulation that plants are adversely affected (Alexander, 1969). However, these considerations are merely hypothetical at this time since they have not been adequately researched.

The large amount of data that has been reported dealing with pesticide effects on soil microorganisms and microbial processes has primarily involved pure culture studies or soil studies in the lab. Such simplified systems are unlikely to accurately reproduce the soil environment (Hill and Wright, 1978). Some of the problems with such approaches have been discussed by Alexander (1977). The problems prevent extrapolation of results to any natural systems and make them useless in the evaluation of pesticides total effect on soil nutrient cycling processes. Also, most studies have applied acute stresses rather than the chronic stresses to which soil microorganisms are typically exposed (Parr, 1974).

Pesticide usage in agriculture has provided a fertile field for the evaluation of impacts at the organismal and process level (e.g., nitrification, mineralization). However, this research has not expanded to test hypotheses relating to changes in whole ecosystems. As an example, the effects of pesticides on nitrification have been adequately tested. However, hypotheses have not been formulated or tested relating the results to natural soil systems or to ecosystem function.

One of the problems associated with certain pesticides is their persistence. The degradation of pesticides in soils and water has been researched with attention being given to the physical, chemical, and biological factors that influence rates of degradation. This has allowed generalizations on the influence of specific factors, such as organic matter content, pH, and temperature on degradation. Continuing studies of this type will be necessary to keep pace with the increasing number of pesticides being used.

Likewise, pesticide runoff from agricultural land has received adequate attention and models have been and are being developed to describe and predict this process. Experimental approaches have also been used so that the effect of different agricultural technologies can be incorporated into the models. These efforts should expedite the formulation of principles that will allow generalizations across different agricultural systems.

In their literature reviews, both Parr (1974) and Anderson (1978) comment on the conflicting nature of data regarding pesticide effects on soil microorganisms. The problem is confounded by authors failing to include enough soil data and background information that might explain the inconsistencies. The result has been that generalizations cannot be drawn from the data presently available. The need for systematic studies using agreed-upon methodology is indicated.

Very little attention has been given to the problem of pesticide synergism. A few reports indicate that synergisms do occur. Lichtenstein et al. (1973) showed that certain herbicides increase the toxicity of a range of insecticides. Likewise, Gomaa et al. (1979) found that herbicides degrade more slowly, with an increase in phytotoxicity, in the presence of the insecticide aldicarb. A National Research Council report acknowledges the seriousness of our lack of knowledge in the area of synergisms and suggests that criteria be established for screening synergisms (National Academy of Sciences, 1975).

Pesticide residues in soils will be present in the soils of a region as a spatial mosaic. No two farm fields will receive exactly the same pesticide treatments for any length of time. Also, the pesticide milieu in a soil is constantly changing as new pesticides enter the market.

Numerous organisms other than insects have become resistant to certain pesticides. In fact, it is almost predictable that species with short generation times and large gene pools will become resistant to a pesticide that is applied repeatedly.

The consequences of the above considerations are that time series or regional analysis of pesticide problems will prove to be quite challenging. One of the aims of the National Pesticide Monitoring Program is to predict changes in residue levels through time. Yet Nickerson and Barbehenn (1975a) using the extensive starling residue data, incorrectly predicted that concentrations of organochlorines in starlings for 1974 would be less than 0.1 ppm. In fact, analysis of the 1974 starling residue levels indicated a mean concentration of 0.282 ppm (Nicherson and Barbehenn, 1975b). Obviously, predictions of ecological changes will be fraught with problems if the behavior of the factors affecting ecosystems is unknown.

Most pesticide impact studies have focused on organisms rather than ecosystem functioning. Studies of ecosystem level processes such as nitrogen-fixation and nitrification have been inconsistent. Considering the very limited data base regarding ecosystem-level responses to pesticides, it would be premature to attempt long-term predictions of pesticide effects on ecosystems.

Lack of data has prevented any modeling of ecosystem effects of pesticides. Such efforts will be premature until sufficient systems-level data has been collected from a variety of agro-ecosystems. Several models dealing with the runoff and leaching of pesticides from agricultural lands are in the literature (Knisel, 1980). These sufficiently describe and predict how pesticides enter aquatic systems as non-point source pollutants. Environmental effects of pesticides in aquatic systems have not been considered in the models. Instead, the models have been used to develop control methods for non-point source pollutants.

The National Pest Monitoring Program gives continuing information on the levels of pesticides in the environment. It indicates the rate at which persistent organo-chlorine pesticides are disappearing from ecosystems. Such information will influence future decisions on the use of long-lived pesticides. Pesticide residue monitoring is sufficiently accurate but not adequate for monitoring ecological impact of pesticide use. The present program emphasizes organismal processes. An ideal program would also incorporate systematic observations of ecosystem-level processes as influenced by pest management strategies. Such an approach would allow evaluation of the response of the entire agro-ecosystem to different technologies.

Since it is the entire ecosystem, and not necessarily component organisms, that provides environmental services, it is the ecosystem that must be monitored, not component organisms (unless a particular organism mediates a key environmental process, e.g., honeybees as pollinators, Azotobacter for nitrogen fixation). The use of "indicator species" may be necessary but not sufficient for impact assessment. Until now, prediction of the consequences of pesticide usage has been based on the observation of indicator species.

Harvest

Secretary of Agriculture Bergland recently suggested that federal funding of mechanized farming might not be appropriate (Marshall, 1980). While his reasoning was that the economic benefits of such research accrues to a very few people while creating the social problem of displaced farm laborers, mechanized farming should also be questioned based on its environmental impacts. Unfortunately, the development of mechanical harvesters considers harvest efficiency and economics without considering long-term environmental impacts. Effects of mechanization might involve air pollution problems, soil compaction, increased surface runoff, erosion and heavy metals in soil, and disturbance of wildlife. Ironically, the mechanical damage to fruit trees and bushes could be severe enough to reduce yields. More insidious would be a long-term gradual decrease in crop production due to increase in disease occurrence due to invasion through plant surface abrasions and broken limbs. Insect pests can also invade via these routes. Loss of leaf surface area due to mechanical harvesting may reduce yields in subsequent years by decreasing the storage of photosynthate and translocation of nutrients out of the leaves prior to leaf fall.

The social and environmental consequences of mechanized harvesting techniques may work against their continued use. In any case, unquestioning acceptance of technology is inappropriate. The need for assessing environmental impacts is indicated.

CONCLUSIONS

Obviously it is impossible to develop agricultural policy which will maintain and enhance environmental services if the relationships between agricultural production and ecological effects are poorly understood. The conflict between maximizing food production and environmental services simultaneously is unresolvable without some way of accounting for and encouraging the services. Encouragement is possible through financial incentives or disincentives, but this is likely to receive opposition from both farmers and environmentalists. A better way is to set policy which recognizes that agriculture, unlike industries using strictly non-renewable resources, is compatible with the production of environmental services.

The increased per hectare production, decreasing labor intensiveness, and aggregation of farms in the last five decades is indicative of government policy which did not understand the concept of a holistic agricultural system. A holistic system can and must be maintaining a healthy environment in order to maintain its own long-term productivity.

Government sponsored research and extension education activities encouraged the changes without adequately promoting the procedures which would have mitigated some of the environmental disservices.

The primary function of an agricultural system is to produce food over a long term. The system must be able to maintain its productivity for this year and succeeding years and generations. On the other hand, the individual farmer must be concerned with making a profit (or at least not going under) from year to year. Thus while farmers are certainly concerned about long-term productivity, they must put most of their effort into short-term productivity. Thus it is necessary for a rational, integrated national agricultural policy to encourage the practices which enhance long-term productivity.

It is just this need for long-term productivity and a holistic view of agriculture which argues against the bandwagon approach for agricultural policy. As we have seen with long-lived pesticides, ill-informed decisions which look at only one sector of the agro-ecosystem can have long-term negative effects on services. Agriculture cannot jump on a bandwagon of, for example, production of biomass energy to meet off-the-farm fuel needs without considering long-term effects of removing more and more organic matter from the land. The focus in agricultural policy needs to be on maintaining the needed level of output to meet domestic (and some foreign) food needs while developing an integrated, self-sustaining farm system.

Farmers and their families are obviously the first to experience and recognize the environmental, social, and economic consequences of their own management decisions. As an example of a complex ecological/

socio-economic problem which derives from technological changes we can look at the deterioration of farm communities. This has taken place due to the conglomeration of small farms into corporation holdings and large family farms and the decreasing labor intensiveness of agriculture. In many parts of the country once thriving farm communities have become cultural wastelands due to the lack of employment opportunities and the discouragement and demeaning of farm labor.

The trend away from diversification towards large scale monoculture has left individual farmers and entire regions of our agricultural system open to disasters such as the corn blight of 1970. It is not that farmers do not remember and understand the old proverb about "not putting all your eggs in one basket," but when you have just invested tens of thousands of dollars in new equipment, it becomes difficult to re-diversify your operation. This gets back to the question of long-term productivity versus this season's profits. The fertilizer manufacturers, pesticide salespeople, and equipment dealers are available to help the farmer increase today's yields. Government activities which do not have to show a profit in dollars but in societal benefit must be designed to encourage sustanability of the agro-ecosystem.

Since the beginning of European colonization of this continent, there has been a prejudice against wetlands, a term previously almost synonymous with wastelands. Farmers often refer to "cleaning out" a piece of bottomland. Much of the finest agricultural land in the central states, particularly the Missouri and Mississippi Valleys was once seasonally flooded bottomland and is now protected by dikes, channel modification, and flow regulation. But now society is expressing its concern about non-point source pollution and pointing the finger of guilt at farmers (among others). It is likely that preserving just a small portion of the bottomlands adjacent to streams in native vegetation would have eliminated much of the non-point source pollution from agriculture.

Once again non-point source pollution is a good example of how society is affected but must not complain too loudly and cause the wrong remedies to be implemented. Non-point source controls which apply management restrictions that lead to significantly decreased yields will increase food prices and diminish our ability to use food as an item in international trade. But non-point source controls which are based on an integrated agro-ecosystem approach to land management can conceivably control pollution sources without reducing yields.

What farmers and conservationists need are new integrated farming systems including recommendations for machinery, fertilizer needs, weed, insect and disease control, tillage systems, suitable plant varieties, and waste recycling while at the same time maintaining management of the air, water, and soil resources in an environmentally acceptable manner. Too often in the past research organizations were hampered in their developing of integrated farming systems by funding being made available on a piecemeal basis. As a result, agricultural scientists from various disciplines have rarely worked together to define a holistic farming operation. A step has recently been taken in the right direction by several investigators in their research on agriculture as an ecosystem. Support for these activities has not come through the classic agricultural research channels but through federal agencies (National Science Foundation and others) who historically support basic scientific investigations. Recognition by agricultural researchers that agriculture is a total system science is only beginning.

The incisive wit who printed the bumper sticker "If You Complain About Farmers Don't Talk With Your Mouth Full" sums up a valid response by farmers to criticism of their management practices. American farmers have increased their per hectare and per person productivity phenomenally at the encouragement of society as expressed through agricultural policy. It is now time for society to promote policies which will diminish the production of environmental disservices and sustain productivity.

RECOMMENDATIONS

1. Designs for future agricultural research need to consider holistic ecosystem level approaches.

2. Effect of agricultural practices on watershed level responses should be quantified.

3. More research needs to be undertaken to identify agricultural effects on biotic components of the output environment.

4. The contribution of residue management to soil fertility and environmental quality should be assessed.

5. The effect of agricultural practices on soil organic matter concentrations should be monitored due to the importance of organic matter in maintaining soil fertility and tilth and preventing erosion losses.

6. Research on the impact of fertilization and increased irrigation on the quantity and quality of the groundwater resource is needed.

7. Contribution of artifically drained fields to pollutant loads in surface drainage should be quantified.

8. Interaction of irrigation and drainage of potentially saline arid lands should be addressed.

9. Attempts should be made to develop a unified data base for irrigation and drainage of agricultural lands.

10. USDA data on water quality should, if possible, be stored as a unified data base or should be entered into the STORET system.

11. Contributions of agricultural areas to non-point source pollution loads should be assessed.

12. Water quality research should attempt to associate output parameters with particular land uses in agricultural watersheds.

13. Interactions of hydrologic response and nutrient movement on agricultural watersheds should be modeled.

14. Effects of riparian vegetation on water quality should be quantified on agricultural watersheds.

15. Environmental considerations should be entered into the calculation of economic action levels in pest management programs.

16. The long-term effect of pesticides on plant production should be an area of concern.

17. A mechanism should be initiated for transfer of technological information on environmental services of agricultural lands.

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Background Paper No. 32

GROUND WATER AND AGRICULTURAL PRODUCTIVITY: THE INFORMATION AND DATA BASE

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ABSTRACT

Declining ground-water availability and quality and related factors will adversely affect the nation's agricultural productivity, especially in the southwest during the next several decades. Ground-water overdrafts, degradation of ground-water quality, decreasing stream flows resulting from ground-water pumpage, water logging and the build up of salts in irrigated soils, and the subsidence and collapse of the land surface due to ground-water withdrawals are the major factors that must be evaluated in the determination of rates of future declines in agricultural productivity.

The water data and information base for evaluating cause and effect relationships that will contribute to future declines in agricultural productivity is obtained largely by governmental entities at the Federal and State level. At the local level county agencies and quasi-governmental entities collect a variety of water data specific to their management needs. The data and information are dispersed among a variety of sources including large federal water data banks. The data available are adequate for planning and policymaking needs, however, considerable effort will be required to aggregate the data into a format usable by policymakers and planners.

I. INTRODUCTION

During the next several decades a marked decrease in the availability and quality of ground water will significantly reduce the productivity of much of the nation's irrigated agricultural land, especially in the southwestern United States. The rest of the country probably will not experience similar severe problems of reduced water availability and declining water quality, but locally, in some eastern states, water shortages and water quality problems will affect agricultural productivity. Because of the overall lack of water in the west, much of the loss of agricultural productivity probably will have to be offset by the development of marginal agricultural lands in the east where water is more abundant.

Changes in agricultural technologies, such as drip irrigation, will reduce the demands on the ground-water reservoirs in some areas. However, the reduction in future ground-water withdrawals resulting from such advanced agricultural technologies will be small. A greater effect probably will result from increasingly efficient use of irrigation waters. However, both advanced technologies and increased efficiencies will only postpone for a few years the inevitable exhaustion of some of the major ground-water reservoirs in the United States. The major changes in agricultural technologies that most likely will be experienced in western States during the coming decades will be the return of irrigated lands to dry land farming or to grazing.

Although some schemes for recharging aquifers experiencing ground-water overdrafts have been proposed, the lack of local sources of water and the high energy costs involved in the transporting and lifting of water from distant sources may preclude or prohibit their implementation. Decreasing supplies and competition for energy, in all of its forms, in the future, will have to be a major consideration in the implementation of proposed schemes, as large amounts of energy are required for the long distance transport and lift of water from remote sources. Schemes for the long distance transport of water probably will have to be evaluated against the alternative of bringing marginal agricultural lands into production or increasing the productivity of existing agricultural lands in eastern States.

Nearly all segments of the nation's agricultural sector are dependent upon ground water. Irrigation is by far the largest agricultural use of ground water, but because of its nearly universal availability, ground water is widely used for stock watering, food and fibre washing and processing, preparation of insecticide and herbicide sprays, and for domestic farm water supplies. All of these uses are essential to the increased agricultural productivity needed to sustain the world's growing population.

The availability and suitability of the nation's ground-water resources for agricultural uses will be adversely affected by a number of changing agricultural technologies and by future land and water use policies as well as by the growing needs of water for energy development. The principal factors related to agricultural technologies that will affect the availability and suitability of ground water for agricultural use and agricultural productivity are:

1) Overdraft (mining) of ground water,
2) The degradation of water quality,
3) Reduction in stream flow and discharge of springs,
4) Water logging and buildup of mineral salts in irrigated soils, and
5) Subsidence and collapse of the land surface.

These factors will be discussed in the following chapter. Chapter 3 will describe the data and the information base that pertains to each of the factors. Chapter 4 describes the adequacy and compatibility of the data and information base for these factors, and Chapter 5 discusses the potential consequences of the inadequacies in the data base and in the analyses of ground-water availability and quality as it pertains to agricultural productivity and changes in agricultural technology.

II. GROUND-WATER FACTORS RELATED TO AGRICULTURAL TECHNOLOGIES THAT AFFECT AGRICULTURAL PRODUCTIVITY

Overdraft of Ground Water

The withdrawal of ground water from an aquifer in excess of the long term rate of recharge is called ground-water overdraft (1) or water mining. The mining of ground water is common in the arid or semi-arid areas of the United States where recharge rates are low. Water is available from these aquifers only because it has accumulated in the ground over a period of many thousands of years.

Ground-water overdrafts result in the lowering of ground-water levels, a reduction in the thickness of water saturated sediments, and in some places degradation of the quality of water in the aquifer. A decrease in saturated thickness reduces the availability of water and declining water levels result in increased pumping lifts and pumping costs. Capital investment in wells and pumps increases as a result of ground-water mining. "As a direct result of large declines in water levels well yields are reduced. In order to meet demands pumps must be set deeper and larger motors installed. In some cases, new wells are needed to meet demands. The improvements cause operating costs to spiral upward. (1, page 48)." Overdrafts eventually result in reduced availability of water or high operating costs, either of which may make it unfeasible to irrigate.

The reduction in agricultural productivity resulting from ground-water overdrafts has been occurring for the past several decades. However, the greatest reductions in agricultural productivity resulting from overdraft should occur in the next three or four decades. In most areas of ground-water overdraft, the loss in agricultural productivity will be permanent as other water is already fully committed to other use and thus is not available to replace the water being mined.

The major areas of ground-water overdraft are in the states of Texas, Nebraska, Colorado, Kansas, Oklahoma, New Mexico, Nevada, Arizona, and California. Major ground-water overdraft problems also are reported in the Lower White River area of Arkansa (2, page 48) and the Souris and Red River Basins in North Dakota and Minnesota (3, page 23).

The most notable area of ground-water overdraft is the High Plains region which extends from Nebraska to Texas including the states of Colorado, Kansas, and Oklahoma. Wells in the High Plains Region tap the Ogalalla Formation, a thick deposit of unconsolidated to semi-consolidated sands and gravel. "The Ogalalla Aquifer in Texas is one of the most intensively developed aquifers in the United States. Pumpage ranges from about 5 to 10 million acre feet annually --and supports more than 65 percent of the irrigated acreage in Texas. This pumpage is considerably greater than the exceedingly small average annual natural recharge to the aquifer.

The decline and ultimate exhaustion of this aquifer will reduce agricultural production, lower supplies of food and natural fibres for consumer markets, raise retail prices for these commodities and reduce employment and incomes for this area. (1)." The exhaustion of this aquifer as a water supply for this major irrigation area is one of the most serious water supply problems of Texas for the remainder of the 20th Century.

Ground-water overdrafts are also a signficant problem in the Winter Garden area of Texas where the Carrizo aquifer, which yields most of the water used for irrigation in the area, is pumped at an average annual rate of

272,000 acre feet, while the average annual rate of recharge is only about 100,000 acre feet (1, page 47).

"In the Roswell Artesian Basin of New Mexico where ground-water withdrawal has exceeded recharge for many years, the Pecos Valley Artesian Conservancy District has been purchasing and retiring irrigated acreage. About 3000 acres have been retired under this program (4, page 28). Other New Mexico areas where ground water is being mined are the Sunshine Valley in Taos County, the Estancia Basin in Sante Fe County, the Hockett area in Dona Ana, Luna, and Sierras Counties, and the Mimbres underground water basin in Luna County. In the Estancia Basin an estimated 5,900 acres will go out of production by the year 2000. Elsewhere in New Mexico the amount of irrigated acreage will be reduced shortly after the year 2000. In the vicinity of Kenmere and Minot in the Souris River Basin of North Dakota and near Hatton in the Red River Basin of Minnesota-North Dakota continued deletion of ground water also could reduce agricultural productivity.

In Arizona the amount of irrigation has remained stable since 1968. Lands going out of production due to causes such as deficient water supplies, uneconomical pumping lifts, and urbanization have been balanced by irrigation on Indian lands and development of previously untapped ground-water sources (5, page 7). The potential for offsetting losses in agricultural production in Arizona through additional development of surface and ground-water sources in the future is severely limited as nearly all known water sources have been fully appropriated or have been already fully developed. In south central Arizona estimated ground-water overdrafts will be 1.4 billion gallons in 1985 and between 2.0 and 2.2 billion gallons in the year 2000.

Nearly all major aquifers presently experiencing overdraft in the arid or semi-arid areas of the Country ultimately will be exhausted. Lower agricultural productivity and reduced economic activity can be expected in these areas.

Degradation of Ground-Water Quality

o Intrusion or Migration of Saline Water into
Fresh Water Portions of Aquifers

Many aquifers contain both fresh and mineralized (saline) ground waters. The lighter, fresh water in such aquifers "float" on the denser saline water. Salt water—fresh water aquifer systems are common and best known in coastal areas where fresh water in the landward part of the aquifer is in contact with salt water in the seaward part of the aquifer. Salt water—fresh water aquifers are also present in many inland areas. When fresh water is pumped from such aquifers, the saline water migrates upwards and towards pumped wells and eventually replaces part or all of the fresh water in the aquifer.

Intrusion or migration of salt water into fresh water parts in aquifers has occurred in many areas of ground-water irrigation. In the Roswell Artesian Basin of New Mexico, the artesian head has been declining for many years and

"This decline has caused saline waters to encroach in the fresh water portion (of the aquifer) east and north of Roswell (4, page 28)." In the Trans-Pecos Region of Texas, ground waters are becoming saline because saline water encroachment and the recycling of water for irrigation. The extensive groundwater declines in the Carrizo aquifer in Dimmit and Zwala Counties, Texas "has caused reversals in the hydraulic gradient of the aquifer, thus allowing poorer quality water to enter areas which previously had good quality water (1, page 48)."

In some places the quality of water in aquifers is degraded by leakage of water from a saline aquifer into overlying or underlying fresh water aquifer via the well bores of improperly constructed and maintained wells or abandoned wells that have been improperly plugged and sealed. In Dimmit County and adjacent areas of Texas, saline water from the Bigford Formation is leaking through old well bores into the underlying Carrizo aquifer (1, page 48). The lowering of the artesian head (potentiometric surface) in the Carrizo aquifer, as a result of pumping for irrigation and other uses, provides the hydraulic gradient necessary for the inter-aquifer movement of water.

The migration of sea water or other poor quality ground water into heavily pumped aquifers commonly results in the production of water that is unsuitable for irrigation or less suitable than the water originally contained in the aquifer. The more mineralized water exacerbates problems of soil salinity and water logging that plague many irrigation projects.

The degradation of water quality in aquifers affected by heavy withdrawals also has a negative impact on non-irrigation uses of water. In the High Plains Region "quality of the ground water declines as the (Ogalalla) aquifer becomes dewatered and in some portions of the region the water has become unsuitable for domestic use. This may have a serious negative impact on the economy of the area (2, page 21)."

The contamination of aquifers by herbicides, insecticides, and fertilizers can also make water unsuitable for processing of agricultural products, stock water, and farm home use.

- Induced Recharge of Aquifers with Saline Surface Waters

When the water levels in an aquifer are lowered as a result of groundwater withdrawals, poor quality surface waters commonly infiltrate into these aquifers. The problem of induced recharge of saline waters to aquifers used for irrigation supply is being exacerbated by the degradation of the quality of surface waters as a result of irrigation and other water use. "Man's use of the regions water has increased the salinity of the remaining flow of the Colorado River through salt loading and salt concentration, evaporation from reservoirs, streams and canals, evapotranspirtion by crops, and exports (of water) causes increased concentration (6)." The degradation of water quality as described for the Colorado River is common in most western streams, and the recharge of poor quality water to fresh water aquifers used for irrigation supply and other agricultural use is an increasing problem in many western states. For example, in the Trans-Pecos Region of Texas the ground waters are becoming saline, in part, from the recycling of waters applied for irrigation. In the San Joaquin Valley in California there is a need for a "valley wide management system which would dispose of and reuse saline water to prevent the ... degradation of surface waters in the San Joaquin River and endangerment of ground-water supplies (7, page 43)."

The contamination of fresh water aquifers through induced infiltration of saline surface waters and agricultural drainage has not received the attention given to other sources of ground-water contamination, but it is a factor that must be considered in long term planning for agricultural productivity.

Reduction in Stream Flow and Discharge of Springs due to Ground-Water Pumping for Irrigation

The pumping of water from wells results in the lowering of ground-water levels in the area surrounding the wells. This lowering of water levels causes a reduction in the natural discharge of water from the aquifer. Much of the natural discharge from aquifers is through springs and through seeps along and beneath streams. If ground-water levels are lowered below the level of a stream, water can infiltrate from the stream to the aquifer, and areas along streams that under natural conditions received water from the ground, become areas where surface water flows into the ground. The decline in stream flow that results from the reduction in ground-water discharge and induced infiltration of surface water reduces the availability of surface water for other uses, including irrigation use.

The changes in the water regimen that can result from pumping of ground water for irrigation may be somewhat beneficial in that water tends to infiltrate into and be stored in the ground during both the irrigation and the off-irrigation season. Water stored in the ground can then be pumped during the irrigation season. Ground-water irrigation, however, requires energy for pumping, whereas irrigation through diversion of surface waters generally is accomplished through gravity flow. As energy costs increase in future decades, less energy intensive irrigation systems probably will take precidence over systems requiring large amounts of energy. Future water-management practices in irrigated areas will require consideration of the effects of pumping of ground water on stream flows as well as the energy requirements of various types of irrigation systems.

The adverse impact of ground-water withdrawals on stream flow must, however, be considered in any analysis of the effects of ground-water availability on agricultural productivity.

Water Logging and Soil Salinity

All natural waters contain dissolved mineral matter. The application of irrigation water, thus, involves the application of mineral salts to the soil. If these salts are not flushed from irrigated soils, the salt content in time builds up to a level where the permeability of the soils is reduced and the soils become water logged and will no longer sustain crop production. Historically, the greatest failures of irrigation projects have resulted from the build up of salts in and water logging of irrigated soils. The irrigation projects associated with Egypt's Aswan Dam are the most notable and recent examples of soil salinity and water logging problems that have significantly reduced agricultural productivity.

The buildup of salts in irrigated soils can be controlled if the soils are adequately drained and sufficient water is applied to flush the accumulated salts from the soil. The quantity of water applied to irrigated lands must include water in excess of that needed for plant growth and soil evaporation losses. This excess water is called the "leaching fraction." The salts flushed from the soil must drain into and through the subsoils and eventually move into surface drains or into the underlying ground-water reservoir. In areas where ground water is in short supply, the quantity of water used for irrigation must be carefully calculated, so only the water that is required for crop use, soil evaporation, and leaching of salts is applied. Water in excess of that quantity reduces the availability of water for irrigation on adjacent lands.

The process of determining the quantity of water to be applied is complicated by the types of soils being irrigated and the quality of the water being applied. Some types of soils irrigated with some types of water are very difficult to drain and leaching of salts is not readily accomplished. In some irrigated areas only a few kinds of crops can be grown due to soil salinization. In addition, the costs of providing the necessary drainage and the lack of the quantities of water needed to leach the salts from the soil may preclude the reclamation of saline soils.

Land Subsidence resulting from Ground-Water Pumpage

The withdrawal of water from aquifers that are in contact with beds of clay and shale of recent geologic origin can result in subsidence of the land surface. The reduction in hydraulic pressure in an aquifer as a result of pumping causes water to move from the shales and clays into the aquifer. When the shales and clays lose water they compact. This compaction results in subsidence of the land surface.

Land subsidence affects agricultural productivity as it interfers with agriculture drainage, stream flow, the transport of water in irrigation canals and aqueducts, and in coastal areas it allows sea water to move further in land in tidal waters. Subsidence also causes the casings of irrigation wells to protrude above the surface and to buckle and collapse below the land surface.

In western Pinal County and parts of the Lower Santa Cruz Basin subsidence has damaged the Picacho Reservoir, water wells, railroads, streams, highways, and agricultural land (8, page 15). Land subsidence also is a major problem in the Santa Clara Valley of California. Near San Jose land subsidence has resulted in the need for extensive levees along streams draining into San Francisco Bay. In the San Joaquin Valley, where an area the size of Connecticut has subsided (9), subsidence has adversely impacted the California aqueduct.

In southwestern Georgia and adjacent parts of Florida, collapse of the land surface is believed to be the result of lowered ground-water levels caused in part by withdrawals for irrigation.

III. THE DATA AND INFORMATION BASE FOR THE GROUND-WATER QUALITY AND AVAILABILITY FACTORS AFFECTING AGRICULTURAL PRODUCTIVITY

The data and information that have been and are being collected for the factors discussed in the previous chapter are voluminous. The collection of the data and information has been stimulated largely out of state and local needs rather than national concerns. Hence, the compilation and analyses of many different types of data and information, collected by many agencies and entities, is required before a national picture of the overall relationship of ground water to agricultural productivity can be obtained.

The National Data Base

Ground-water data are available from several national data banks maintained by the U.S. Geological Survey and other Federal agencies. A summary of the collection, storage, retrieval and publications aspects of water resources data is presented in Circular 756 of the U.S. Geological Survey.

- WATSTORE, the Water Data Storage and Retrieval System of the U.S. Geological Survey

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics. The files of primary interest evaluating the ground-water availability and quality situation in respect to agriculture are the Water Quality File, the Ground-Water Site Inventory File, and the Station Header File which serves as an automated index from which a retrieval list of stations, such as all ground-water sites in a single county, can be obtained. Data can be retrieved from these files in machine readable form as well as by computer listing. The data can be read for computer application programs. Hence, the data can be reduced by computer application to number of forms much more usable than simple listings.

WATSTORE contains all water data collected by the U.S. Geological Survey through Federal and State/Federal cooperative programs. Water data collected by some but not all State water agencies are also included in the system.

- The Catalog of Information in Water issued by the Geological Survey's Office of Water Data Coordination

Every other year the Office of Water Data Coordination issues its catalog of Information on Water Data, which is a compilation of data activities of about 20 Federal agencies and about 300 other entities mostly State agencies. The catalog is published in 21 volumes, a separate volume for each of the 21 water planning regions of the Water Resources Council. These catalogs do not give specifics on the data collected, but provide summary information on the data stations of the contributing agencies.

- NAWDEX — The National Water
  Data Exchange

A NAWDEX program office has been established within the U.S. Geological Survey to assemble knowledge as to the location of all types of water data. The office's function is to prepare and maintain an index to water data activities that ultimately will include information on all water data in the files of member units of NAWDEX.

- The Geological Survey's Regional
  Aquifer-System Analyses (RASA) Program

The RASA program is a systematic effort to study regional aquifer systems which together cover much of the country. Each RASA study will be designed to fit the particular problems of the study area. The general approach will be to develop a computor simulation (model) of the overall system supported by more detailed simulation of local problem areas. The studies will assist in an understanding of change brought about by human activities and in predicting effects of future stresses. In some areas effects such as land subsidence, change in water quality, and costs of pumping will be investigated in corollary simulations.

State and Local Data Bases

Although much of the data and information related to ground-water availability and quality is collected through the U.S. Geological Survey's cooperative programs with State and local agencies and is thus included in the WATSTORE system, some State and local agencies maintain their own data collection and storage systems. The Texas Department of Water Resources, for example, maintains its own water data collection network and water data storage file, but most of the water data collected by the State of Texas are not included in WATSTORE.

Programs for the collection of ground water and related data pertinent to agricultural productivity vary significantly from state to state (Table 1). The emphasis given to programs for water data collection in a given state generally reflect the level of water problems existing in the state. In states where ground water is extensively used for irrigation the data collected are sufficiently accurate and timely for present and future water management and policy decisions, except, for the collection of water use and ground-water pumpage data for which more accurate data are needed.

The Information and Data Base for Ground-Water Overdrafts

Data needed to determine if ground-water is being mined from an aquifer and the rate that water is being mined from an aquifer are: 1) the rate of ground-water withdrawal, 2) the rate of natural recharge and discharge, and 3) the potential for reducing natural discharge and increasing recharge when water levels in the aquifer are lowered by pumping.

For aquifers such as the Ogallalla Formation of the High Plains where the rates of natural recharge and discharge are exceedingly low, as are the potentials for increasing recharge or reducing natural discharge, the rate of overdraft is for practical purposes equal to the rate of pumping. Withdrawal rates can also be determined by calculating the volume of sediments being dewatered, which is a function of the rate of water level decline and the area of the aquifer being dewatered. In most areas where water is being mined water level declines are the primary data used to evaluate rates of overdraft. For the irrigator whose primary concern is pumping cost, depth to water and water-level change data are of primary importance.

Quantification of the natural rates of recharge and the potential for inducing recharge from lakes or streams and for reducing the rate of natural discharge are essential to the determination that overdraft is occurring or will occur and of the existing and potential rates of overdraft. Data and information on rates of natural recharge, sites and rates of natural discharge, sources and potential sources of induced recharge to an aquifer are determined through investigations of ground-water basins, regional aquifers and county or regional ground-water or hydrologic studies. Such data is contained in publications of Federal and State agencies and must be obtained largely on a case by case basis.

Ground-water level data in agricultural areas are collected primarily by State agencies and the U.S. Geological Survey under a State/Federal cooperative program. Some states, however, have their own data collection networks as do some local agencies, such as Water Conservancy Districts. Although some observation wells are equipped with continuous water-level recording instruments and some are measured several times a year, the great majority of observation wells are measured once a year during the off-irrigation season when water levels are relatively stable and the local effects of pumping are minimal.

As most water-level data networks are maintained by State agencies or under the cooperative program of the Geological Survey with State agencies, data on ground-water levels are published for each state generally on an annual basis either by the State agency or by the Geological Survey. Table 1 lists the types of water-level data collected in several western states where ground-water overdrafts in agricultural areas occur or potentially may occur. The table contains information on some of the types and format of water-level reports published for some states.

Data on rates of water level declines are available from WATSTORE. In order to obtain water-level data pertinent to ground-water withdrawals for agricultural uses, however, it is necessary to specify the area for which water level are desired as WATSTORE does not differentiate water-level data on the basis of factors causing water levels to change with time.

The data on water levels in State reports and in WATSTORE provide sufficient information on water-level decline, through time to identify all areas where ground-water overdraft is affecting or potentially will affect agricultural productivity. An accurate determination of actual rates of overdraft requires data on ground-water withdrawals which in conjunction with data on recharge provides the information needed to determine rates of overdraft. Data on rates of ground-water withdrawal are available from a variety of sources, however, the ground-water withdrawal data networks are incomplete and apparently the methods provide for considerable descrepancy between the estimates obtained. Table 2 lists ground-water withdrawal estimates made by Federal agencies and by State-Regional agencies for water planning regions of the Water Resources Council where irrigation pumpage is a major factor. As rates of agricultural withdrawal are determined largely by indirect means such as fuel and electrical consumption or acreage and types of crops grown, the reason for the difference in data provided are understandable.

The Information and Data Base for Ground-Water Quality Changes

A large amount of ground-water quality data are included in WATSTORE (table 3). The data on ground-water used for irrigation can be retrieved from WATSTORE on the basis of use category and location of the well sampled. Data can also be obtained from annual reports published by the U.S. Geological Survey and State agencies.

Networks for the repetitive collection of ground-water used for irrigation are being developed or expanded in many States. The relatively slow change in water quality in most aquifers used for irrigation apparently has precluded strong emphasis on the development of such networks. Intensive water-quality networks generally are maintained, some by local agencies, such as Water Conservancy Districts where the quality of ground water used for irrigation is rapidly deteriorating or is of marginal quality for irrigation and careful application is required to prevent soil salinization and water logging of soils.

Data on Reduction in Stream Flow and Discharge of Springs

Data needed to determine how stream flow and springs will be affected by ground-water pumpage require data on the hydraulic characteristics and geometry of the aquifer being pumped and the degree of hydraulic connection between the stream and the aquifer. Such data, obtained through areal water investigations, are published in various reports of Federal and State agencies. Quantification of potential reduction can best be determined through simulation (models) supported by stream flow data. Stream flow data can be obtained from WATSTORE and data on aquifer characteristics are given in reports of various ground-water studies.

Data on Water Logging and Soil Salinity

Soil salinity and water logging problems are largely controlled by well established techniques. However, where adequate supplies of water of suitable quality are not available, some irrigated lands are going out of production. The rate of loss of irrigated land in the Nation could increase sharply in the next several decades owing to declining ground-water quality. Records of loss of land as a result of salinity and water logging probably are maintained only by local agencies.

Data on Land Subsidence caused by Ground-Water Pumpage

In most areas of land subsidence data are collected largely by state and local agencies. In California, the U.S. Geological Survey in cooperation with the State of California maintains a network of land subsidence stations and wells. The data on subsidence appear to be sufficiently accurate and adequate for all agricultural planning purposes.

IV. POTENTIAL CONSEQUENCES OF THE LACK OF DATA AND ITS COMPATABILITY FOR ANALYSIS

The Adequacy of Data on the Changes in the Ground-Water Resources for Formulation of Scientific Principals

Data that have been collected on the effects of various ground-water resources development practices throughout the past several decades appear to have been adequate for the formulation of the general scientific principals needed for water management. For example, the work C.V. Theis and others in the study of the ground-water development in the High Plains area of Texas and adjacent states, clearly established the potential for mining water from the Ogalalla Formation. Although the scientific principles involved were clearly established, mining of ground water in the High Plains has continued to the present time without abatement, except for the limitations provided by the reduced availability of water and the high costs of pumping.

The declining availability of ground water for future agricultural productivity apparently does not stem from a lack of data or of knowledge of the scientific principals involved. Rather, it is the lack of clear policy on how our resources should be used, and the development of the basic philosophy on which that policy must be based. The lack of persuasive argument, for example, that justifies the saving of water stored in the ground for use at some future date, and the general lack of a legal means of preventing its use, both past and present, has permitted the extensive ground-water overdraft that has and is occurring in the many western States. The high probability that agricultural productivity in the High Plains Region would decline during the latter part of the twentieth century and that economic problems would consequently emerge in that area, were clearly recognized both locally and nationally for the last several decades.

Established scientific principals of water occurrence provide the means for "optimum" management of the ground-water resources as it relates to agricultural productivity. For example, scientific knowhow has been widely used in the control of soil salinization and soil water logging because the scientific techniques involved have provided immediate payoff. The lack of application of scientific principals in water management and planning probably lies in the lack of a national resources-use philosophy on which water management policy can be based.

Aggregation of Data for Regional Analysis of Problems Related to a Changing Ground-Water Resource

The ground-water data from different time periods and different sources is presently being aggregated and analyzed under the Geological Survey's RASA program, which is scheduled for completion in 1988. The aggregation of the data and its analyses is inhibited in these studies only by the complexities of the systems involved and difficulties inherent in developing accurate simulation models of complex systems.

Although the RASA studies require the collection of additional geological and hydrological data, existing data appear to be adequate for predicting future declines in agricultural productivity resulting from reduced ground-water availability and declining water quality in sufficient detail for policymaking needs. Aggregation of the information in a form usable and understandable by policymakers would require considerable aggregation and analysis of existing data. This could be readily accomplished through inter-agency federal task force or a private firm. As the information is available, if the proper sources are tapped and can readily be put into useful format, the lack of data or its analysis have not inhibited the development of national agricultural policy as it relates to the use of the ground-water resource. The legal and institutional barriers involved in the use and regulation of ground water (16, page 11) probably constitute the chief impediments to the formulation of policy.

Use of Models in Ground-Water Resources Planning

The long-term effects of continued use of ground water for irrigation on the availability and quality of ground water for other uses, as well as the effects of ground-water overdrafts and deteriorating ground-water quality on future agricultural productivity can be predicted through the use of numerical and other analog models. The use of models has grown rapidly in the last decade as a result of the development of modeling techniques and computers capable of handling the numerous calculations involved. The process of determining how accurately a model simulates a real aquifer can best be determined by comparing stress and effect (strain) relations obtained from the model with historical stress and effect relations observed in the real aquifer. This is accomplished by stressing the model at the same rate the real aquifer was stressed and comparing the effects of stress observed in the model with the effects observed in the real aquifer. One of the major problems with varifying the accuracy of many aquifer models, however, is the lack of accurate historical data on the rates of withdrawal of water from the aquifers. The problem of determining the historical rates of withdrawal (pumping) from an aquifer is shown by the data on pumpage of ground water in the 21 regions studied by the Water Resources Council as indicated in Table 2. The difference in the State and Regional estimates and the Federal estimates on the quantities of ground water withdrawn,undoubtedly results from indirect rather than direct measurements of ground-water pumpage. Ground-water withdrawal rates commonly are estimated indirectly from other data such as the amount of acres irrigated, the type of crop grown, and the amount of fuel or electricity used in pumping. The lack of accurate data on rates of ground-water withdrawal for irrigation complicates the use of models to predict future pumping, ground-water level drawdown, water availability and water quality relationships.

The determination of potential loss in agricultural productivity owing to lowered ground-water levels and deteriorating ground-water quality are compounded by economic factors. Escalating costs of energy and low agricultural prices during the past several years probably is one of the major factors causing irrigated lands to go out of production. The ultimate model required for prediction of future losses in agricultural productivity should integrate the costs of energy, capital investment in pumps and wells, and prices of agricultural commodities with the prediction of water-level changes, declining availability of ground water, and changes in ground-water quality.

V. DATA ON THE GROUND-WATER RESOURCE AS IT RELATES TO GOVERNMENTAL POLICY

The data and information base for ground-water availability and quality, and related data, are very large. Although the information is dispersed among many sources, with moderate effort the data can be assimilated into a form that will provide policymakers with adequate knowledge required for formulation of agriculture and water-use policy. It appears, however, that concerns over future agricultural productivity have not been sufficient to stimulate an overall review of how changing ground-water availability will affect the nation's production of food and fibre over the next several decades.

The formulation of public policy to compensate for the predicted decline in agricultural productivity will require information beyond that acquired by the water-resources "community." Most proposed programs to compensate for the forthcoming decline in agricultural productivity of lands dependent on ground water for irrigation will be energy intensive. Competing demands for energy and energy availability will also be required in the formulation of new agricultural policy.

National agricultural policies that probably have the greatest effect on the use of the ground-water resource are economic. For example, the quantity of water used to irrigate rice in Arkansas doubled between 1970 and 1975 as a result of a relaxation of acreage controls (11, page 9). Studies are needed to determine if acreage controls and crop price support programs result in ground-water pumping for irrigation that would not be economically feasible without these government programs.

Most individual farmers fully understand the costs and risks of their decisions to continue to pump water from aquifers experiencing overdraft or declining water quality. The individual farmer, however, is left with little choice except that of using the water under his own land in a manner that will maximize his profits. If he does not pump the water from beneath his lands, his neighbors will do it for him, as the water does not recognize farm boundaries. Investment in land and equipment probably preclude the joint action of farmers to save water for some future date when needs for food and fibre and prices paid for agricultural commodities will be higher. The spectre of low agricultural prices and high production costs in areas of major ground-water overdraft undoubtedly inhibit the individual farmer's decision to invest in expensive technologies to save water.

Society may suffer in future decades as a result of past, present, and future exploitation of the ground-water resource. In an era of excess agricultural productivity, however, it appears that it would be difficult to implement a national policy for conserving the ground-water resource for future use even if the legal basis for such a policy existed.

Table 1. A Brief Summary of Data Collection Programs and Data Publication Formats of Several Western States*

ARIZONA. Ground-water level and quality data are collected by the U.S. Geological Survey as part of a State-Federal cooperative program. Some 200 wells are measured as a part of a statewide network. In irrigation areas the wells are measured during the non-irrigation season. In addition, ground-water, quality of water, and ground-water pumpage rates are inventoried in about 5 of the 60 hydraulic basins in Arizona every year. Emphasis in this inventory is placed on rapidly developing basins.

The Salt River Project makes quality of water analysis of their irrigation wells. An annual report is published on ground-water conditions in Arizona. The latest report (10) is in map form and shows the location of the observation wells, the change in water levels for the period 1974 - 1979, and annual ground-water pumpage data.

ARKANSAS. Ground-water level and water-quality data are collected by the U.S. Geological Survey in cooperation with the Arkansas Geological Commission. The state observation network includes some 580 wells; about one-third of these reflect water-level changes due to pumping for agricultural uses. Quality of water data are collected from a network of about 25 wells, however, only a few of these are irrigation wells. Water quality data are collected, however, as a part of ongoing areal investigations. Data on ground-water used for irrigation are collected every five years (11). Water-level data in tabular, graphic and map format are published annually (12).

CALIFORNIA. Under its Federal-State cooperative program the U.S. Geological Survey maintains a statewide index well observation program. Water levels are measured twice annually in the 600 to 700 wells in the network. The wells are sampled for water quality analysis every four years. Other water level and water-quality data are collected as a part of ongoing areal investigations. The Geological Survey also maintains a land subsidence observation well network.

Most of the water data collected in California is obtained by County Flood Control and Water Conservation Districts. The Districts collect water level, water quality, and ground-water withdrawal data. Most of the data collected by the State reportedly is not placed in WATSTORE.

Beginning with the 1980 water year, data on ground-water levels, quality and pumpage are to be included in the Annual Water Data Report prepared by the U.S. Geological Survey. Data on land subsidence resulting from ground-water withdrawals are published separately from the water data report.

COLORADO. Ground-water level and water-quality data are collected in Colorado by the U.S. Geological Survey as part of the cooperative program with the Colorado Department of Natural Resources, Division of Water Resources, Office of the State Engineer. About 1000 observation wells that are affected by agricultural activities are measured in the Spring before the start of the irrigation season. Although a water-quality network is not maintained, some data on the quality of water yielded by irrigation wells are obtained through other investigations. A ground-water pumpage data collection program is being initiated. Ground-water level information are published annually in open file reports of the Geological Survey. Ground-water level data for the period 1974-78 for the High Plains area in Colorado were published in 1978 (13).

NEVADA. Ground-water level and quality data are collected under a cooperative program between the Nevada Division of Water Resources and the U.S. Geological Survey. The Geological Survey maintains a statewide network observation well network which includes about two dozen wells whose water levels are affected by agricultural activities.

The Nevada Division of Water Resources also collects ground-water level data in agricultural areas. Data collected by the State are not entered in the Geological Survey's WATSTORE file.

Neither the Geological Survey nor the Nevada Division of Water Resources maintains a network for repetitive collection of water quality data for ground waters used for irrigation. Most water quality data in Nevada are collected by the Nevada Division of Environmental Protection. Apparently, a ground-water pumpage data collection program has not yet been implemented in Nevada.

Ground-water quality and water-level data are published annually in a report entitled "Water Resources Data for Nevada." The report for 1978 lists data only in tabular form.

NEW MEXICO. Ground-water data collected primarily under a Federal-State cooperative program between the U.S. Geological Survey and the Office of the

State Engineer. The basic observation well network maintained under this program includes about 2,500 wells. Measurements are made in the winter non-irrigation season. Water-quality data for aquifers used for irrigation are collected on an average of once every five years, except where poor quality water is causing soil salinity problems north and east of Roswell. In that area annual samples are collected. The Roswell Conservancy District makes some water level measurements and the Rio Grande Conservancy District has a small water-quality sampling program.

TEXAS. The water-level observation network in Texas is maintained by the Texas Department of Water Resources. Some 8000 wells are included in the entire observation well network. About 2,700 of these wells reflect water level changes resulting from irrigation withdrawals. Approximately 800 of these 2,700 wells are measured by Irrigation Districts of the High Plains for the Department of Water Resources.

Although water-quality networks are being developed, periodic sampling of the quality of water yielded by wells tapping major aquifers has not been completed except in some areas of the High Plains as a part of the Regional Aquifer System Analysis program of the U.S. Geological Survey which is being completed on a cooperative basis with the Texas Department of Water Resources and other State agencies. A program for measuring groundwater pumpage for irrigation has not been implemented on a statewide basis. A report published by the Texas Department of Water Resources (14) provides water-level data for the Southern High Plains of Texas during the period 1971-77.

UTAH. Ground-water level and quality data are collected by the U.S. Geological Survey as a part of the cooperative program with the State. The observation well network includes about 1000 wells and about 40 percent of these wells are affected by agricultural activities. Ground-water pumpage data are collected in cooperation with the Office of the State Engineer. Withdrawal rates are collected from electrical and fuel consumption data.

The quality of water network includes about 250 wells that are resampled about every two or three years. Data are published annually in reports prepared by the U.S. Geological Survey in cooperation with the Utah Division of Water Resources. The report for 1980 (15) contains hydrographs and maps showing annual declines in ground-water levels. Data on ground-water withdrawals are also provided for the major irrigation areas in the State.

* Data obtained through a telephone survey with various State and Federal officials.

Table 2. Differences in Federal Estimates and State/Regional Estimates of Ground-Water Withdrawals in Water Resource Council Planning Regions where Irrigation Use is a Major Factor (Data in million gallons per day)

Region and Number		Estimates of Federal Entities	Estimates of State/Regional Entities
South Atlantic-Gulf	(3)	5,449	7,037
Upper Mississippi	(7)	2,366	2,127
Lower Mississippi	(8)	4,838	6,413
Souris-Red-Rainy	(9)	86	374
Missouri	(10)	10,407	4,196
Arkansas-White-Red	(11)	8,846	6,968
Texas Gulf	(12)	7,222	7,172
Rio Grande	(13)	2,335	1,722
Upper Colorado	(14)	126	105
Lower Colorado	(15)	5,008	4,324
Great Basin	(16)	1,424	20
Pacific Northwest	(17)	7,348	7,348
California	(18)	19,160	12,510
Hawaii	(20)	790	882

Data from "The Nation's Water Resources, 1975-2000," Vol. 2, Part V; U.S. Water Resources Council, 1978.

Table 3. Ground of Water Data Sites Stored in WATSTORE for Selected States — June, 1980

State	Surface Water Quality Sites	Ground-Water Quality Sites
ARIZONA	885	7745
ARKANSAS	717	5993
CALIFORNIA	3087	10480
COLORADO	2687	5921
FLORIDA	4128	25877
IDAHO	1508	2394
KANSAS	772	754
MINNESOTA	1184	2096
MONTANA	1344	5184
NEBRASKA	698	2388
NEVADA	391	507
NEW MEXICO	958	5180
OKLAHOMA	1080	3111
SOUTH DAKOTA	446	2911
TEXAS	1304	7633
UTAH	1730	3763
WYOMING	1649	6371

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Background Paper No. 33

PRODUCTIVITY OF SOIL AS RELATED TO CHEMICAL CHANGES

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ABSTRACT

Chemical changes occurred rapidly in soils continuously cropped during the early history of the United States. The changes resulted in depletion of chemical elements essential for plant growth. The early agricultural practices were exploitative. Nutrients were being mined from agricultural soils by harvested crops. Loss of nutrients from surface soil by erosion accelerated the rate at which productivity of land declined.

Research has shown that crop production does not have to exploit one of our nation's most valuable natural resources, the soil. Crops remove more chemical nutrients from the soil than ever before, because of the higher yields obtained today. Soil productivity is maintained and enhanced by application of fertilizers and liming materials to replace nutrients removed in crops. Improved technology for the manufacture, transport, and application of fertilizers has contributed much by allowing growers to maintain chemical levels in soil that promote high crop yields.

Producing high crop yields has a self-perpetuating effect. Lush plant growth protects the soil from erosion during the growing season. After harvest, crop residues remaining in fields have a favorable effect on soil physical, chemical, and biological properties.

It is in the grower's best interest that proper chemical levels be maintained. Chemical soil tests are used to evaluate a soil's ability to supply nutrients to plants. Fertilizer recommendations are based on the soil test values. Summaries of soil tests, by state and regions over time, offer a good means for monitoring chemical changes in agricultural

soils. Improved technology for equipment and instrumentation used in soil test laboratories has been a boost for soil testing programs.

Maintaining favorable nutrient levels in our soils will be accomplished rather easily as long as adequate supplies of fertilizers are available and at reasonable costs. Natural gas is used in the manufacture of nitrogen fertilizers. Should shortages of natural gas occur, governmental agencies will likely need to give fertilizer manufacture a high priority or else unfavorable chemical changes in soils will occur.

PRODUCTIVITY OF SOIL AS RELATED TO CHEMICAL CHANGES

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INTRODUCTION

Man's survival has depended on plants grown in the thin mantle, called soil, that covers part of our land surface. Man may eat plant products directly. He may indirectly use plants for sustenance by eating animals that earlier ingested plants for growth and survival. Plants capture and store energy from the sun. This energy becomes available for our bodily functions after we eat plant products. Plants are a renewable source of energy during each growing season. In addition to food, man has depended on plants grown in soil for clothing, shelter, and numerous other uses such as a source of energy for keeping him warm and cooking his food.

Some plant materials that grew many, many years ago have been stored deep underground and are recovered for our use today. Coal and petroleum are such materials. This paper will be concerned with growing plants that are used by people soon after their production.

Early man was a hunter and gatherer rather than a tiller of the soil. He hunted wild animals, got fish from streams, and gathered edible fruits, seed, and tubers that were produced by Mother Nature. When man became a tiller of the soil, he learned that plant growth and crop yields on a given field decreased with time. Since man's awareness that continuous cropping decreased soil productivity, he has been concerned with how to restore productivity to the soil. This understanding came slowly for many centuries, but much has been learned about the chemistry of soils and plant growth in the last 100 years.

Plant growth is dependent, among other things, on certain essential chemical elements being in the soil solution that surrounds roots. Determining the optima concentrations of elements required for high crop yields has been studied much. The second phase of research has been to study means for attaining then maintaining those desireable concentrations in the soil solution. Much progress has been made through improved technology.

Technological advances in many areas have found application in agriculture. In this century, tractors have largely replaced animal power for tilling the soil. Technological advances in the manufacture, transport, and application of fertilizers have played a major role in increasing crop yields. Herbicides have aided greatly in reducing competition for unwanted weeds. Other chemicals, now commonplace, protect crops from insects and diseases while growing and while in storage.

Adoption of new technology has often resulted in considerable changes in crop production practices. An example is the substitution of tractors for mules and horses. When animals were used for power, close-grown forage legumes were grown in rotation with row crops to provide hay for the animals. Disappearance of work animals from farms meant that hay acreage could be reduced and replaced by row crops. Cultivated row crops often make the soil more susceptible to erosion and, consequently, lowered productivity (as discussed later, other improved practices can prevent this from occurring in many areas).

Manure imparts desireable properties to soil. Once work animals were replaced by tractors, an on-farm source of manure was also gone. This hastened the need for the use of more fertilizer to provide some of the essential elements which formerly were recycled on the farm in manure.

Technology has altered many crop production management practices that have permitted more intensive cropping. The result has been much more food production for a world that is desperately in need of eliminating human hunger.

There is no need for excessive alarm about the very intensive cropping of many acres in the United States today. Soil is different from many of our other natural resources. Coal is gone and cannot be used again once it is burned. Soil does not wear out with continued use, provided we are good stewards and manage it properly. Good soil stewardship includes protecting it from erosion, replenishing essential nutrients removed during cropping, and preventing the accumulation of substances that are detrimental to plant growth.

Farmers know that their livelihood is dependent on a productive soil. Strong economic forces motivate growers to attempt to maintain the soil's chemistry such that plant growth is optimized. Growers maintain the desirable chemical aspects primarily by the addition of fertilizers and liming materials. Allowing the soil to become deficient in essential nutrients reduces crop yields, and, consequently, profits to growers. Adding soil amendments in excess of that required for optimum plant growth increases production costs without an increase in returns. Fertilizer use will be discussed more fully in another report by another author.

Problems associated with poor management of soil chemical properties are not serious on many of our cultivated acres. It is a matter that requires continuous vigilance though, as soils may quickly become depleted in essential plant nutrients when cropped. Soil tests are readily available for use by growers to assess the soil's ability to supply adequate amounts of essential nutrients to plants. There are good and poor farm managers and all do not utilize soil tests to monitor soil chemical properties. Some fields are deficient in essential plant nutrients while a smaller number may have excesses. Nevertheless, we generally have knowledge of ways to adjust soil chemistry to make the soil productive. Agreed, the proper practices are not always put into use by all growers.

The chemistry of disturbed soils, as occurs with strip mining, is more difficult to control and is often extremely costly. Also, some soils in drier regions of the western United States have never been cultivated because of their high content of chemical salts. Some of these areas have been made suitable for cropping where irrigation water is available for leaching out the salts.

All the desired information on soil chemistry and crop production is not known. But, much information is available from public and private sources. Also, farmers learn much from their neighbors and from their own experiences.

A special situation is where agricultural land is used to dispose of materials such as sewage sludge and industrial waste. Such land will require extra attention and monitoring if it is to be chemically acceptable for growing plants.

We are being friendly to our soils when we manage them for high production. Current high production begets future high production because of favorable effects from large amounts of crop residues added to soils.

ORGANIC COMPONENT OF SOILS

Agriculturists have long known that organic matter content of soils was highly correlated to productivity of soils. Loss of organic matter from soils of the eastern United States, with a concomitant loss in productivity, was one motivating factor for pioneers to move west. Organic matter contained chemical elements that are essential for plant growth. These essential nutrients had been accumulated and stored in forest litter over a period of many years. After clearing the forests, the organic matter was a reservoir of essential plant nutrients that became depleted as our forefathers tilled the soil. Nutrients "trapped" in organic form were changed (mineralized) to inorganic forms which were then available for uptake by their crops. As cropping continued the organic matter reservoir was unable to supply enough essential nutrients for high crop yields.

Organic matter was the soil component that had a disproportionate share of the ill effects of erosion, Jenny (1933). This is because organic matter is highest in topsoil and this is where erosion occurs. The soil lost by erosion contained a higher amount of organic matter than the soil that remained behind. As life-sustaining topsoil with its high content of organic matter was eroded, many of our forefathers moved west in quest of more productive soil.

Although not as essential for plant growth and crop production today as in yesteryears, soil organic matter is highly desirable. Organic matter has an indirect effect on crop growth as it affects factors that have a direct effect on plant growth. Organic matter affects chemical, physical, and biological properties of soils. Some effects of organic matter follow.

1. When decomposing, it supplies chemical elements essential for plant growth.

2. Increases the negative charges (cation exchange capacity) associated with the solid fraction of soils. This means it increases the ability of the soil to retain cations in plant-available forms rather than have them leach deeper than the rooting zone.

3. Increases the amount of stable soil aggregates. This in turn increases the rate at which water infiltrates soil and, consequently, reduces water runoff and soil erosion.

4. In addition to item 3, organic matter itself increases the water holding capacity of soil.

5. Organic matter improves soil tilth. It makes the soil easier to till and with less energy requirement. Similarly, organic

matter reduces soil crusting and thereby aids seedling emergence. It reduces soil compaction which otherwise would be a deterrent to crop growth by reducing root growth and restricting aeration.

6. Organic matter helps to deactivate certain compounds that may be potentially harmful to plant growth. This occurs by adsorption and other means.

Changes in Soil Organic Matter

Nitrogen content of soils is highly correlated with organic matter content of soils. This is because about 95% or more of the nitrogen in soil is in organic matter, and the percent nitrogen in soil organic matter is fairly constant. For the above reasons, many researchers have measured soil nitrogen and used it as an index of soil organic matter. Multiply nitrogen by 20 to convert to organic matter in topsoil.

Jenny (1933) measured the effect that years of cultivation had on the content of nitrogen in soil, Figure 1. Nitrogen content declined rapidly during the first few years of cultivation. Under average farming conditions that prevailed in the Midwest prior to 1930, Jenny estimated that the decline in nitrogen content of soils was 25, 10, and 7% for the first, second, and third 20-year periods, respectively.

Hobbs and Brown (1957) found that from 40 to 45% of the soil organic matter was lost from 1916 to 1946 when cropped with milo and kafir at Hays, Kansas. Their results agreed with Jenny's in that the most rapid loss occurred during the early years of cropping.

Does organic matter content of soil necessarily have to decrease rapidly with cropping? Results from the Morrow Plots in Illinois indicate that the decline in organic matter greatly depends on the cropping system and amendments applied to soil. The plots were started in 1876 but soil organic matter was not measured until 1904. Soil treatment to some plots was also started in 1904. Prior to that time, the study consisted only of different cropping systems.

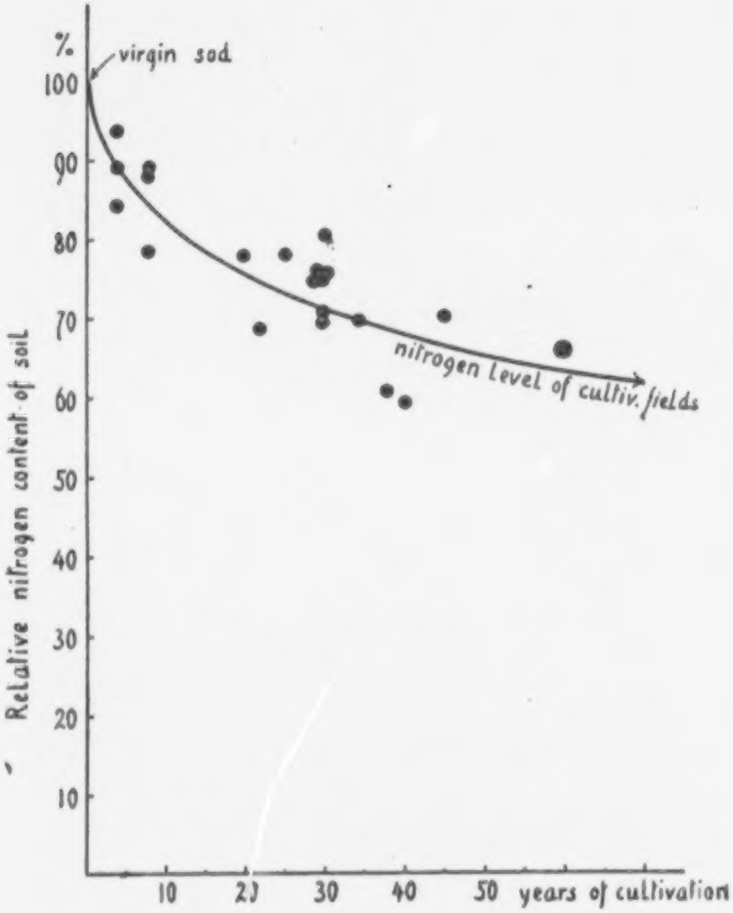

Figure 1. Decline in nitrogen content of soil with length of cultivation under average farming practices in the Mid-west prior to 1930, Jenny (1933).

Without soil treatment, 39% of the organic matter in 1904 was lost by 1973 with continuous corn and 24% with the 3-year rotation of corn-oats-clover, Table 1. With soil treatment, the decline in organic matter was much less. Furthermore, the decline with treatment was similar (7 and 8%) for the two cropping systems.

Soil treatments increased crop yields. This means that more organic materials were added to the soil on the treated plots as compared to untreated plots. Little erosion occurs on the Morrow Plots because of their nearly flat topography. Had the plots been on steeper land, part of the beneficial effect of soil treatment reducing loss of organic matter could have been attributed to better protection from erosion because of more plant growth.

Table 1. Organic matter content of Morrow Plots in 1904 and 1973 as affected by cropping and soil treatment, Welch (1976).

Cropping System	Soil treatment*	Organic matter, T/A		Percent loss of organic matter from 1940 to 1973
		1904	1973	
Continuous corn	Untreated	41.2	25.0	39
	Treated	37.1	24.6	7
Corn-Oats-Clover	Untreated	58.8	44.5	24
	Treated	56.7	51.9	8

*The Morrow Plots were started in 1876. Soil treatment of manure, lime and phosphorous additions to certain plots were not started until 1904.

Consequences of Changes in Soil Organic Matter

Almost everyone would agree that organic matter imparts characteristics to soils that are favorable for crop production. There is not full agreement as to how organic matter should be maintained, or even the necessity of specifically attempting to maintain it.

Some feel that organic matter is so important to crop production and have depended on it to the extent that they are called organic farmers, (Report and recommendation on organic farming, prepared by USDA study team on organic farming, July 1980). They rely little or not at all on conventional inorganic fertilizers that are commercially available (Lockeretz, et al., 1978).

Other farmers know the importance of soil organic matter but do not depend on manures and forage legumes to maintain organic matter. Instead they use inorganic commercial fertilizers to grow large amounts of organic materials that are added to soils in the crop residues. Their goal may be to grow high yields of corn grain, but, in so doing, they are helping to maintain soil organic matter by adding the vegetative parts to the soil. Either this system or the one used by organic farmers can successfully maintain soil organic matter if good management is used in both cases.

Any differences in crop production would not be because one system used organic materials to supply essential plant nutrients while another system used inorganic sources to provide nutrients. The reason is that plants do not absorb nutrients in organic form. Even though added to soil in organic materials, the nutrient must be released from the organic materials and transformed to inorganic forms. The plants absorb inorganic nutrients irrespective of whether initially added as organic or inorganic sources.

The effect of organic matter on soil properties has been discussed earlier.

A decrease in soil organic matter is not an irreversible process. Should a decrease in soil organic matter occur to the extent that soil productivity is greatly reduced, the situation can be reversed. Increasing the organic matter content of soils is a slow process, unless large amounts of organic materials are easily available from a source other than the field under consideration. It can be done though.

Rasmussen, et al. (1980) indicated that about 4,500 pounds of crop residues per acre per year would be required to maintain soil organic matter in a wheat-fallow system in Oregon. Larson, et al. (1972) stated that about 6,000 pounds of cornstalks per acre per year would maintain the organic matter content of Iowa soils planted to continuous corn. Additions of plant material greater than the above values would increase soil organic matter while lesser amounts would result in a decrease. Adding 8 tons of cornstalks per acre per year in the Iowa study increased soil organic matter by 47% when compared to removal of all cornstalks.

I calculated that about 7,000 pounds of cornstalks per acre were added to Illinois fields planted to corn in 1979. The calculation was based on the average grain yield of 128 bushels per acre, our highest ever. The United States average yield of 109 bushels in 1979 would have associated with it about 6,000 pounds per acre of above-ground vegetative material, most of which would be added to the soil.

Research Underway on Changes in Soil Organic Matter

Changes in the amount of organic matter in soils occur relatively slowly. Research of several years duration is required to properly document the effect of cropping systems, soil treatments, and other management practices on the organic matter content of soil. Few of these types of studies have been initiated in recent years. One reason is that many agronomists and soil scientists feel that the effect of many management practices on soil organic matter are reasonably predictable. Another reason may be that, due to the nature of the research, results do not lend themselves to frequent publication in scientific journals. Still another reason is that funding from various agencies is generally not as readily available as for some shorter-term research of greater interest to the funder. An exception to the above are studies started in recent years where large amounts of organic waste materials are supplied to a small land area. An example is the application of sewage sludge to agricultural land. Funding for these types of research has been available, and organic matter content of soil may be quickly increased. Another type of study that has recently received considerable interest is where the entire above-ground portion of grain crops may be removed to produce energy from biomass, Larson (1979). Such studies would be concerned with the effect of vegetative removal on the content of soil organic matter and future productivity of the soil.

Data for the effect of management practices on organic matter content of soils must come mostly from research initiated several years ago. Many of those studies have now been discontinued. Some long-term studies with the above objective are still underway. Notable among them are the Morrow Plots in Illinois and Sanborn field in Missouri. European studies include those of Rothamsted Experimental Station at Harpenden, Herts., England and those at Grignon, France.

Research on organic matter changes is being conducted mostly at Land Grant Universities in various states and by the Federal agency, ARS/USDA/SEA. In such studies, organic matter is generally measured only once every 3 to 6 years. This is because changes in the amount of soil organic matter occur slowly, and one could not expect to be able to sample the soil and analytically determine the change due to a few hundred pounds of organic matter with a background of 40,000 pounds per acre, i.e., the amount already present in the plow layer of some soils. Most studies have been concerned with changes in the plow layer rather than throughout the rooting depth.

Relation Between Soil Organic Matter and Agricultural Technology

Technological advances have had a big impact on the organic matter content of soils. The early effect of some technology was to cause a decrease in organic matter, but later developments have tended to increase, or at least maintain, organic matter levels.

Virgin soils developed under grass have a high level of organic matter. The advent of the steel plow allowed pioneers to break the sod for cropping. Tillage and cropping caused a decline in organic matter.

Farmers once depended on horses and mules for power. During the last 5 decades, tractors have largely replaced animal power on farms in the United States. Close-growing forage legumes were grown on the farm to provide hay for the horses and mules. These hay crops helped protect the soil from erosion, and soil organic matter lost by erosion was less with hay than with cultivated row crops. The horses and mules provided manure (organic material) on each farm. The manure was spread on the soil. After the appearance of tractors, the work animals disappeared. In the absence of work animals, the need for hay diminished. Acreage that once grew hay was diminished. Acreage that once grew hay was diverted to cultivated row crops like corn.

Technological advances in the manufacture, transportation, storage, and application of fertilizers have done much to arrest the decline in soil organic matter in soils of the United States. Fertilizers increase plant growth. Increases or decreases in soil organic matter are closely related to the amount of crop residues added to soils. Fertilizers account for greater amounts of crop residues being added to soil.

Melsted (1954) wrote 25 years ago that tillage and management practices being tested in the Midwest represented a philosophy of maximum crop production per acre with minimum soil deterioration. "The philosophy is based on the concepts that high production is good for the soil, that minimum tillage promotes soil tilth and conserves soil organic matter, that high fertility promotes high yields and lessens the loss of soil humus (organic matter), that large amounts of decomposable organic matter in the soil are essential to good soil tilth and good soil physical conditions, and that cover in the form of both living and trash mulches is good protection against all forms of erosion". If erosion is reduced, loss of soil organic matter is reduced.

Stirring the soil during seedbed preparation and cultivation increases oxygen level in the soil and hastens decomposition of soil organic matter. Cultivated row crops usually cause a more rapid decline in organic matter than close-grown crops. Technological advances in herbicides and farm machinery allow no-till systems to be followed for crops that have often had both extensive seedbed preparation and cultivation, Moody, et al. (1961) and Triplett, et al. (1963). Herbicides control weeds rather than being dependent on cultivation. The no-till or reduced tillage systems leave more residue on the soil surface than conventional systems and affords the soil more protection against erosion.

Soybeans have traditionally been planted in rows 30 inches or wider that would permit cultivation for weed control. Herbicides now allow soybeans to be drilled in rows too narrow to cultivate that produce higher yields than wider rows, Burnside and Moomaw (1977). Wide rows for mechanically controlling weeds in soybeans is being replaced by narrow rows and chemical weed control. Less tillage should aid in maintenance of soil organic matter.

Recent advances in confinement feeding of livestock, particularly hogs, have permitted easier means of collecting manure. Advances in farm equipment make it easier to spread the manure on agricultural soils. The same equipment used to spread livestock wastes may also be used to apply sewage sludge from our cities. Addition of these organic materials should help maintain or increase soil organic matter.

Many advances in farm equipment now permit field operations to be performed more timely. An example is planting corn early. The early planting results in higher yields with more residues returned to the soils, as compared to late planting and lower yields. Generally, any production practice that increases crop yields is helpful for maintaining or increasing the content of organic matter in soils.

Improved technology has resulted in greater plant growth with more organic materials to be added to soils. Technology has not yet produced an economically feasible compound which will substitute for organic matter with regard to imparting the same desirable physical properties to soils.

There is a broad data base for assessing the effect of many crop production practices on the content of soil organic matter. Practices adopted as new technology emerges have been those aimed at increasing crop yields. Although not adopted specifically because of their favorable effect on soil organic matter, the effect has been just that.

Research data are not as readily available for documenting the effect of some recently adopted cropping practices. Examples are practices discussed earlier such as no-till or reduced tillage systems, and narrow-row soybeans. However, the effect of such practices should be reasonably predictable based on our current understanding of soil organic matter.

Most of the available data are for cropland rather than rangelands. The reason is that the rangelands are not disturbed by tillage, and concern has been aimed mostly at the much more intensive systems of cultivated, row-crop agriculture.

INORGANIC COMPONENTS OF SOILS

The solid fraction of most soils is composed of from 95 to 99% inorganic materials and the remainder organic materials. Both inorganic and organic soil materials play an important role in crop production. The organic fraction of soils was discussed earlier in this report.

Nutrients essential for plants must be dissolved in the soil water before they are absorbed and utilized in plant growth. Of the total amount of essential nutrients in the soil, only a small fraction is available in solution at a given time for utilization by plants. For example, the plow layer of a soil may contain 45,000 pounds of total potassium per acre, yet only 300 pounds may be in a chemical form available for plant use during the growing season. As nutrients are removed from soil solution by plant uptake, nutrients previously in an unavailable form go into solution. This transformation of certain nutrients from unavailable to available forms is so slow in most soils that it is not possible to produce high crop yields for sustained periods without fertilizers. Fertilizers are added to increase the amount of nutrients available for plant use, with a subsequent increase in crop yields.

Agriculture was an exploitive venture in the United States for many years. The soil was mined of essential plant nutrients as they were removed by harvested crop. Nutrient deficient soils became commonplace, and only low crop yields could be obtained from such soils. One of our nation's most valuable resources was deteriorating and becoming unproductive. It was not until technology permitted the commercial development of fertilizers that the situation was changed.

Plant growth is dependent on many factors other than an ample supply of plant nutrients. Water is often the most limiting plant growth factor in large areas of the United States. Addition of chemical fertilizers will not increase crop yields as much when water is in short supply as when it is adequate.

Rangelands in the United States are in the more arid western states, as contrasted to eastern states. Fertilizer use is largely confined to cultivated acres rather than rangelands. The low rainfall in rangeland areas has prevented the profitable use of fertilizers. Also, because of lower crop yields and subsequent nutrient removal, some rangeland soils have not yet developed nutrient deficiencies. Less intensive soil weathering in the drier regions means that less nutrients have been lost by leaching.

Irrigation has transformed rangeland into cultivated agriculture in many western states. Soils in those areas now receive chemical fertilizers.

Inorganic Excesses and Deficiencies

Deficiencies of inorganic chemicals in agricultural soils is much more commonplace than excesses. Much attention has been given to waste materials that were buried in land fills years ago and their hazardous nature has only recently become public knowledge. Materials such as radioactive waste require special handling and disposal and such materials are beyond the scope of this discussion. Nonhazardous inorganic waste materials are applied to agricultural land with the primary goal being one of disposal rather than one of benefiting plant growth. Guidelines are provided to disposers so that application rates will not generate excesses that threaten the quality of food and water. By far the greatest amounts of inorganic chemicals added to soils are intentional and are added as fertilizers because of benefits expected therefrom.

It is generally known what levels of inorganic chemicals are required in soils for high crop yields. Growers strive to have the proper amounts of essential plant nutrients in soils, because this assures that they will reap the greatest profit. Nutrient deficiencies result in lower crop yields, and chemical excesses from fertilizers represent an unnecessary capital expenditure. There is a strong profit incentive for growers to avoid both chemical deficiencies and excesses in their soils.

Agricultural experiment stations in all states have contributed knowledge toward the proper inorganic chemical levels needed in diverse agricultural soils. This knowledge has been disseminated to growers through the Extension Service administered in each state. Agri-business has also had an educational role with growers.

Growers monitor their soils through chemical tests made on samples from their fields. These chemical tests are made by laboratories operated at land-grant universities or by agri-business. Technological advances in atomic absorption and spectrophotometry equipment allow rapid and relatively inexpensive chemical tests on soils. Improvements in soil test procedures have done much toward enhancing the monitoring of agricultural soils for inorganic nutrient levels.

Research by land grant universities was largely responsible for determining the optima levels of soil nutrients. However, it is results from chemical tests made on samples submitted by growers to soil test laboratories that largely monitor chemical deficiencies or excesses for large acreages. Many states have annually summarized results of soil samples submitted to their laboratories. This affords a convenient way of monitoring chemical changes in agricultural soils with time. In addition, special surveys have been made such as the one in Illinois by Walker, et al. (1970).

As indicated earlier, the problem in agricultural soils has largely been one of chemical deficiencies rather than excesses. The goal has mainly been one of applying chemical fertilizers to eliminate deficiencies in order to increase food production per acre. Much has been achieved toward the goal in the last two decades.

Eliminating chemical deficiencies is a continuing process. Some nutrients such as nitrogen are not readily stored in the soil because they are easily lost by leaching or other means. Nitrogen is applied each year that nonleguminous crops are grown. Other nutrients are also applied on a continuing basis, but less frequently than nitrogen since they are not readily lost from soils. Calcium and magnesium are primarily supplied by liming materials which are generally applied to soils only once every 4 to 8 years.

Soil test summaries for Iowa (Eik, 1980) and Michigan (Personal communication with D.D. Warncke and L.S. Robertson, Michigan State University, 1980) indicate progress toward eliminating soil phosphorus deficiencies in those states, Tables 2 and 3.

Table 2. Changes in soil test phosphorus and potassium in Iowa soils.

	Percentage of total samples that tested low and very low for:	
Period	Phosphorus	Potassium
1950's	67	26
1964-67	60	16
1968-73	52	22
1974-79	39	18

Table 3. Changes in soil test phosphorus and potassium in Michigan soils.

	Soil test, Lb/Acre	
Year	Phosphorus	Potassium
1962	24	115
1967	34	151
1970	45	165
1973	57	153
1976	67	148
1979	85	155

Soil test summaries from many states indicate that soil phosphorus and potassium levels need to be increased on many fields (W.L. Nelson, Paper presented at North Central Soil Fertility Workshop, St. Louis, Missouri, November 1978 entitled Soil Test Summaries and Their Interpretation). According to Nelson "with few exceptions, states west of the Mississippi River show 60-90% testing medium or less in phosphorus. With few exceptions, states east of the Great Plains show 50-70% testing medium or less in potassium".

Nutrient status of soils differs among states. This is due to both inherent fertility levels and differences in the amount of fertilizer used. Welch (1972) showed how fertilizer added versus nutrients removed in harvested crops had changed in Illinois since 1940. Added phosphorus and potassium fertilizers were only 5 and 3%, respectively, of crop removal in 1940. In 1969, additions were 67 and 30% greater than the amounts removed in harvested crops. During the 30-year period, fertilizer use allowed Illinois farmers to go from an era of nutrient depletion to an era of nutrient build-up in their fields.

Rates of Changes of Inorganic Chemical Excesses and Deficiencies

The previous section discussed how soil nutrient deficiencies are being eliminated through the use of chemical fertilizers. Data were presented from certain soils to indicate the build-up of nutrient levels in certain states, and especially in the case of phosphorus and potassium.

Most states east of the Mississippi River do not have a soil test for nitrogen. This is because of the transient nature of inorganic nitrogen in soils (Welch, 1979). It is not practical to build-up the inorganic nitrogen level in soils except to meet the nitrogen requirement of the immediate crop. This is because nitrogen is readily lost by leaching and denitrification (gaseous losses of nitrogen due to bacterial action). In lower-rainfall states west of the Mississippi River, leaching losses of nitrogen are not as great. A soil test for inorganic nitrogen has proved helpful when making fertilizer nitrogen recommendations in some of the western states.

Agronomists and soil scientists with land grant universities often report chemical deficiencies or excesses for large geographical areas. These data are often obtained by the scientist from data of individual fields and farms. Data for individual fields are the result of growers sending in soil samples to soil test laboratories. Results of chemical soil tests performed on growers' samples provide the basis for making fertilizer recommendations. So while scientists may actually write the reports on chemical changes in soils for large areas, it is largely soil samples taken by growers that provide the data for the chemical status of soils.

Numerous scientific studies have been conducted and reported on how chemical changes occur in soils with cropping with and without added fertilizer. Such studies have been extremely helpful in calling attention to the levels of soil nutrients required for high crop yields. But, because of the large numbers of samples taken by growers, their results are generally used to determine the trends toward deficiencies or excesses for large geographical areas. As noted earlier, some systematic surveys for the chemical status of soils for large areas have been made by scientists (Walker, et al., 1970).

Most states have a public soil testing laboratory that is under the auspicies of either the land grant university or the state department of agriculture. Summaries of the results of the chemical tests are periodically prepared on a state basis. Frequency of the soil test summaries vary from state to state, but several states prepare summaries on an annual basis.

Chemical tests made on growers' soil samples are as requested by the growers. The most common tests, by far, are determining the need for limestone (measuring pH) and phosphorus and potassium fertilizers. Analyses for chemical elements such as calcium and magnesium are becoming more commonplace, and, in some areas, analyzing for some of the micronutrients such as zinc is gaining in prominence. Technological advances in instrumentation have been such that many nutrients that were previously laborious to determine may now be rapidly determined.

In rare cases, chemical soil tests are made for elements other than those essential for plant growth.

Soil from research plots may be analyzed for diverse chemicals, depending on the objectives of the research. Several heavy metals may be of interest from soils that have received large applications of municipal or industrial waste.

Chemical content of plants is sometimes used to monitor the soil's ability to supply nutrients to plants. Plant analysis may also be used to determine the content of elements that may be undesirable in the food chain. Chemical soils tests are used much more extensively than plant analyses for determining chemical deficiencies or excesses in soils.

Chemical soil tests are made on soil samples from all states. This means that measurements for chemical deficiencies and excesses are made for diverse soils, climatic, cropping, and management conditions.

Causes and Consequences of Chemical Excesses and Deficiencies

Chemical deficiencies in soils are much more prevalent than chemical excesses when judged by their adverse effects on crop production. In some cases, soils were inherently deficient in some essential plant nutrients, In other cases, soils have become deficient because of chemical losses due to: (1) crop removal, (2) erosion, (3) leaching, (4) volatilization, and (5) denitrification. Nitrogen may be lost by all five of the aforementioned mechanisms. Most of the other essential nutrients are lost only by the first three ways.

Chemical excesses may be naturally occurring or man-made. These excesses adversely affect chemical, physical, and biological properties of soils with respect to their crop production capability. Naturally occurring saline and alkali soils contain excessive amounts of chemicals such as sodium and potassium. Such soils occur primarily in the low-rainfall western states.

Chemical excesses in soils may be created by man. Irrigation water high in chemical salts may result in chemical excesses in the soil that render it less productive. It is accidental when chemical excesses are generated by fertilizers. Chemical excesses may be created unless prudence is used when applying large amounts of waste materials to small land areas.

Excesses of a particular chemical element sometimes occur without additions of the element to soils. This may occur because of changes in soil properties that influence the effective level of the element. Certain forms of aluminum are toxic to plants while other forms are not. Toxic forms of aluminum increase as soils become more acid. Liming soils reduces aluminum toxicity because aluminum is changed to non-toxic forms. Good soil management practices prevent these types of chemical excesses from occurring.

A farming system geared for high food production has as one of its goals the prevention of both chemical deficiencies and excesses. Many more farmers are attaining that desired goal today than ever before in the history of United States agriculture.

The consequences of chemical deficiencies and excesses in soils is poor plant growth. Deficiencies are much more commonplace than excesses. Both can be corrected. Deficiencies are eliminated by chemical additions. Excesses can be lowered by removal in harvested crops. The rate at which excesses are lowered depends on the particular chemical element in excess and crops grown. Deficiencies are so much more prevalent than excesses that emphasis will be given to deficiencies in this discussion.

Poor plant growth as a result of chemical deficiencies triggers a series of events. Growers feel the first effect through lower profits. The less protected soil, due to poor plant growth, is more subject to erosion. The eroded soil fills streams and reservoirs and lowers water quality. With lower crop production, society here and abroad would be faced with rapidly rising food prices.

Everyone and everything wins when the chemical content of soil is maintained at levels that produce high yields. The soil benefits because of the greater protection from erosion during the growing season, and because of the greater amounts of crop residues added to the soil after harvest. People everywhere benefit because of the more abundant supply of food. Farmers gain financially from the current high yields produced, and their soil has been made better for continued high crop yields in the future.

Agricultural Technologies

Some technology, when viewed by itself, may hasten the development of nutrient deficiencies, but other technology is applied to prevent deficiencies from developing. Plant breeders may develop a higher yielding variety. The very fact that the new variety yields higher means that more nutrients will be removed from the soil at harvest than with a lower yielding variety. But, the grower who plants the higher yielding variety will likely apply more chemicals as fertilizers to replace those removed. The overall effect of improved technology has been to prevent either deficiencies or excesses.

Improved non-agricultural technology may impact crop production. For example, efforts are being made to reduce the amount of sulfur dioxide in the atmosphere. One way this has been done is to reduce the amount of sulfur released to the atmosphere by coal-burning industries. The amount of sulfur dioxide in the air over Illinois was only about one-third as much in 1976 as in 1967 (1976 Annual Air Quality Report, Illinois Environmental Protection Agency). The reduced level of sulfur dioxide in the air means that the amount of sulfur added to soil in precipitation is reduced. Thus, the technology that allows removal of sulfur gases from smokestacks will hasten the development of sulfur deficiency in agricultural soils. Sulfur deficiency is easily eliminated by adding sulfur fertilizer to soil.

Nutrient deficiencies lower productivity of land. Data in Table 4 are indicative of how nitrogen deficiency affects corn yield. Without added nitrogen fertilizer corn yield was only 48% as much as compared to where adequate nitrogen was supplied.

Table 4. The effect of added nitrogen on corn yield (Welch, 1979).

Added Nitrogen, Lb/A	Corn yield, Bu/A
0	75
30	100
60	117
90	131
120	142
150	150
180	154
210	155
240	155

Hanway, et al. (1962) reported on a potassium study conducted in several North Central states. They graphically illustrate how corn yield increase due to potassium fertilizer is inversely related to the amount of soil test potassium.

Chemical excesses and deficiencies, irrespective of their causes, result in decreased crop yield. Improved fertilizer technology makes it easy to eliminate deficiencies. Agricultural technology has not generally been responsible for chemical excesses that may occur. There are isolated instances that may be considered an outgrowth of certain technological improvements, i.e., livestock confinement operations, Manure from such operations may result in excessive chemical salts if applied at too high a rate. Chemical excesses can be avoided by simply applying the manure to a large land area. When properly managed, agricultural technology has been a big factor in allowing growers to attain the high crop yields of recent years.

Numerous references could be cited for the relation between crop yields and the supply of essential plant nutrients in soils. It is well documented that improved fertilizer technology has contributed much toward increasing crop yields per unit land area (Black, 1968; Nelson, et al., 1968; Olson, et al., 1971; and, Tisdale and Nelson, 1975).

Adequacy and Compatability of Data and Analysis on Chemical Changes

Data are generally sufficint for predicting rates, causes, and consequences of chemical changes in conventional cropland and rangeland. Cropping patterns and yields for different regions provide data for calculating nutrients removed in harvested crops. Data are available on the amounts of nutrients added for various crops as chemical fertilizers. These data plus regional summaries of soil tests from farmers' fields provide a base for predicting the chemical status of soils in different regions of the United States. Data on crop acreages and fertilizer use are compiled by states, regions, and the United States (Commercial fertilizers. Consumption for year ended June 30, 1979. U.S. Department of Agriculture, Crop Reporting Board, Washington, D.C.; 1980 Fertilizer situation. U.S. Department of Agriculture. FS-10, December 1979).

Causes and consequences of changes in the amounts of primary plant nutrients (nitrogen, phosphorus, and potassium) are more predictable than for micronutrients such as zinc, iron, boron, molybdenum, and copper. Soil tests for predicting the response of crops to micronutrients are not as reliable as those used to predict the response to primary or major nutrients.

Private agencies, in addition to governmental ones, project the need for fertilizer manufacturing facilities in a given region. Fertilizer needs are projected largely from cropping acreages and nutrient removals. Amounts of fertilizer required to prevent soil deficiencies from developing provide the basis for deciding if additional fertilizer manufacturing facilities are needed in a given region.

There is generally good agreement concerning how conventional agriculture affects chemical changes in soil and the short and long-term consequences of chemical changes. Not so well understood are land areas that have been subjected to non-conventional types of agriculture. For example, strip mining for coal may leave surface soil with considerably different chemical properties than possessed by undisturbed soil. Additional research is needed to determine what is required to restore productivity to such disturbed areas. Not all of the loss in productivity can be attributed to chemical changes as physical properties are also altered in the mining operation. Disturbed areas and those agricultural areas used for waste disposal need special consideration when predicting or correcting chemical changes, but such areas are only a small fraction of the conventional agriculture acreage.

Farm management practices that utilize new technology are generally extensively researched before widely adopted by growers. The effect of new management practices on the chemical changes in soils is reasonably predictable. However, rather than merely predicting chemical changes, the actual changes that occurred are measured by chemical soil tests. The chemical changes that occur are generally reversible. If technological advances have an adverse effect on soils, the practice can be terminated and the soil restored to its former level of productivity. Most technological advances used in agriculture were designed to improve productivity of the land.

Although a formal mathematical model may not always be used, farmers and their advisors can generally predict the effect of new technology on productivity of land. Their predictions are precise enough that we surely can expect applied technology to increase crop yields per unit land area.

Consequences of Data or Analysis Inadequacies

Most governmental agencies seem to have an understanding of the role of fertilizers in maintaining the proper levels of essential plant nutrients in soils. The manufacture of nitrogen fertilizers requires large amounts of natural gas. Government policy should give fertilizer manufacture a high priority in the event that natural gas has to be rationed. Proper chemical levels in soils can be maintained provided we retain our capacity to produce the needed quantities of fertilizers. Without an understanding of the importance of replacing chemicals removed from soils through years of cropping, some governmental agencies may have sought to restrict use of fertilizers.

Most farmers understand that nutrients removed in harvested crops must be replaced if productivity is to be maintained or improved. Their profit motive is a strong incentive for them to maintain chemical levels that produce high crop yields. Society benefits from high yields of high quality produce. This is one reason that such a small part of American's budgets go for food, as contrasted to societies in many other countries.

Research has done much to increase crop yields in recent years. It is unlikely that rapid increases in crop yields will continue without a strong program of agricultural research in the future.

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Background Paper No. 34

WIND EROSION AND CONTROL TECHNOLOGY

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WIND EROSION AND CONTROL TECHNOLOGY

N. P. Woodruff

ABSTRACT

Wind erosion and control technology are discussed under eleven headings in this report. Wind erosion processes are briefly described. The history of the problem and its magnitude and consequences are presented. Factors governing the amount of erosion that will occur during any given erosion event are detailed. The "golden" or "cardinal" principle of wind erosion control i.e. keep the land surface covered with vegetation or vegetative residue is discussed as are the four other principles of control. Use of stubble mulch tillage, windbreaks, surface roughening and seven other practical methods of applying current technology are discussed. An attempt is made to put the wind erosion problem in perspective in relation to other agricultural problems -- it is not the greatest problem facing agriculture today. Six possible modifications of current technology and eight new technology ideas, some directly related to wind erosion control and some concerned with areas closely related to wind erosion control, are presented. The role of legislative, regulatory, and institutional mechanisms is discussed in two sub-sections, one dealing with mechanisms that inhibit and the other with mechanisms that facilitate control and repair of wind erosion. Finally with deference and considerable trepidation six funding and leadership things that the Congress can do to improve use of wind erosion control practices are respectfully presented.

WIND EROSION AND CONTROL TECHNOLOGY

N. P. Woodruff[1]

How Wind Erosion Occurs

Wind erosion most simply defined is removal and transporation of soil by wind. It occurs when a strong turbulent wind blows across an unprotected soil surface that is smooth, bare, loose, dry and finely granulated. Soil particles start to move when wind forces overcome gravity. Minimum windspeed required to start movement depends on the size and weight of soil particles and the friction provided by neighboring particles. Where a mixture of single-grained materials is present, the practical windspeed to initiate movement under field conditions is about 13 miles per hour measured at a height of 1-foot.

After soil particles start to move, they are carried by the wind in three types of movement - suspension, saltation, and surface creep. Dust particles less than 0.1 millimeter (0.004 inch) in diameter are lifted into the airstream where they float and are carried in suspension for many miles before being redeposited.

Coarser particles in the size range from 0.1 to 0.5 millimeters (0.004 to 0.02 inch) move in a bouncing or jumping action called saltation. They rise almost vertically, rotating at several hundred revolutions per second, travel 10 to 15 times their height of rise, and return to the surface at forward and downward angles of 6 to 12 degrees. When they strike the soil surface, they break down clods and crusts and dislodge more particles.

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Most of the disloged particles in the size range from 0.5 to 1.0 millimeters (0.02 to 0.04 inch) roll and move by *surface creep*. Winds of extremely high velocity may move particles larger than 1.0 millimeter (0.04 inch), but particles about 0.1 millimeter in diameter (0.004 inch) are most erodible.

Soil blowing usually starts on exposed knolls or hilltops, in tracks or paths made by implements or animals, and in corner turn rows where excessive turning and cultivation have pulverized the surface soil. Once blowing begins from these points, the jumping soil particles severely abrade the surface. The *abrasion* breaks down clods, destroys stable crusts, and wears down vegetative residues and living vegetation. Increasing numbers of particles are set in motion as erosion moves downwind. Such increase in soil flow is called soil *avalanching*. Soil flow is zero at the windward edge of an eroding field but the rate increases leeward until it reaches the maximum that a given wind can carry. The distance downwind at which maximum rate of flow occurs varies with soil erodibility. The more erodible the soil, the greater the rate of alvanching and the shorter the distance to maximum flow.

The mechanics of this extremely complex process have been well documented elsewhere (1, 2, 3, 4, 5, 6, 7).

History of the Wind Erosion Problem

Wind erosion is closely associated with drought, strong winds, and kind of agriculture e.g. small grain production like wheat which is generally grown on flat, treeless plains where winds have an unbroken sweep, particularly during those times of the year when the crop provides little ground cover. The climate and crops of the Great Plains in the United States meet these criteria and it has a long history of wind erosion. Most of it has occurred after virgin lands were broken and planted to cultivated crops, but there was some before the soil was cultivated (8, 9). Weather records reveal major duststorms in 1854-60, 1864-65, 1874, 1880, 1890-94, 1901, 1910-14, 1917, 1919, 1922-23, 1934-39, and 1954-57.

The drought and duststorms of the 1930's were by far the most serious experienced and the ones that demonstrated the tremendous power of the weather to affect the quality of our enviornment and even to control the lives of individuals and communities. These were the storms that brought the words "black blizzard" and "Dustbowl" to our vocabulary and produced the vivid descriptions of the hardships inflicted on people and their mass exodus from the Great Plains area in John Steinbecks' "The Grapes of Wrath". More than 6.5 million acres of land were put out of production and nearly 6.2 million acres suffered serious wind erosion damage (10). Dodge City, Kansas, had 120 days of blowing dust during the fall-to-spring blow season of 1935-36. Some animals suffocated, and sickness noticeably increased among the people in the area. In 1935, hospitals in the heart of the dust bowl reported 233 patients suffering from acute respiratory infections and 367 with air tubes leading to the lungs blocked (11). Thirty-three of those patients died. No records are available of those who suffered similarly but who did not enter hospitals because of lack of funds for medical care. Conditions were nearly as bad in 1934 when 115 patients were reported with similar ailments and 15 died. The situation was so bad that the young farmer, Lawrence Svobida, closed his book "An Empire of Dust" (12), written in 1938 after he had endured 9 years of extreme hardship in the Dustbowl at Meade, Kansas, with the words "My own humble opinion is that with the exception of a few favored localities, the whole Great Plains region is already a desert that cannot be reclaimed through the plans and labors of man."

The wind erosion and duststorms occurring in the 1954-57 period were serious in terms of acres of land receiving some damage, about 16 million acres during the 1954-55 blow season, but there were less than half the number of dusty days as in the 1930's and the effect on crop production and hardship to the people was much less than in the 1930's. From this and from our experience since the 1950's we know today that author Svobida's 1938 evaluation was too severe and that the Great Plains has not become a desert but rather, in some years at least, an abundant supplier of food. In any discussion of the wind erosion problem it is important that we ask ourselves why this has happened. It has been because of a unique combination of the resilent resourcefulness of the sturdy people on the land, applying new technology, availability of better farm machinery and crop varieties, use of fertilizers and chemicals, irrigation, and economic assistance in the form of government conservation programs.

While there are some perceptions and attitudes toward the wind erosion problem, which we will discuss later in this report, that inhibit wind erosion control generally the farmer on the land today is more knowledgeable about wind erosion and its control than his predecessor of the 1930's. If he is an older man he learned some valuable lessons in the 1930's. If he is a younger man, he is probably better educated through formal schooling or through the valuable assistance he receives through the Soil Conservation Service and University Extension Service and he is more willing to accept and apply control technology.

It is well known that development of new wheat and sorghum varieties and the use of commercial fertilizers has markedly increased food production from the Great Plains but better machinery produced by manufacturers of farm equipment has also contributed immeasurably to better wind erosion control. The manufacturers have provided larger more efficient machines, many of which have introduced more effective and new kinds of tillage action. Manufacturers organizations such as the Farm Equipment Institute and the Farm Equipment Manufacturers Association have promoted a better understanding of equipment requirements and applications through meetings and conferences with farmers and federal and state research and action agency groups. All of the companies carry out extensive research programs to improve present lines of equipment and to develop new machines. Development of subsurface sweep machines, which have advanced the stubble mulch system of farming has probably contributed most to wind erosion control but development and improvement of drills and planters to plant in heavy residue and development of machines for subsequent cultivation operations after initial sweep tillage also have provided better wind erosion control.

Irrigation has had a substantial effect on wind erosion and its control. Where it has been developed on sandy marginal lands there is evidence of a potential negative effect on wind erosion control but generally the effect is positive. The drilling of deep wells and the use of center-pivot irrigation systems has put many thousands of acres of dryland under irrigation. Better soil moisture has lessened wind erosion potential but more importantly the greater quantities of residue produced have provided more abundant cover to protect the land.

Economic assistance has come through a number of federal programs first initiated in the 1930's and 1940's. Public Law 46, 74th Congress, HR 7054 "An Act to Provide for the Protection of Land Resources Against Soil Erosion and for Other Purposes" enacted in 1935 added considerable impetus to establishing better control practices (13). Then in 1956, after the drought of the 50's enactment of the Great Plains Conservation Program provided a means to further minimize the climatic and other hazards of farming and ranching. Through this program, landowners received federal payments for fulfilling contracts to do such things as plant cropland to grass, control brush etc. The program has also stimulated farmer and rancher use of stubble mulch tillage and grazing management. All of these practices have contributed directly or indirectly to controlling wind erosion and the financial assistance has made the farmers' economic situation much more tenable and in many cases has been the difference in applying or not applying a given practice.

Development of new technology and a better understanding of the wind erosion process has also contributed substantially to better wind erosion control and to the contradiction of Mr. Svobida's 1938 prediction about the Great Plains. The history of research and investigation of wind erosion began in the later part of the 19th century.

King (14), Udden (9), Free and Stuntz (15), and Bennett and Lowdermilk (16) among others published about wind erosion and methods of control. However it took the Dustbowl disaster to inspire those remaining on the land and the government to begin conducting systematic research to discover how soils are eroded by wind and what control technology can be used to prevent damage. Chepil, Milne and Doughty in Canada; Von Kármán and Malina in California; Joy in South Dakota; Whitfield in Texas; and Bagnold in England pioneered this research effort (17). After World War II an intensive research program was started in cooperation with Kansas State University at Manhattan, Kansas under authority of Public Law No. 46 with funds from the Research and Marketing Act of 1946. A laboratory was constructed and equipped with wind tunnels, soils laboratories, greenhouses and the latest data acquisition systems to study wind erosion and its control. This research continues and is now supported with funds administered by the USDA-Science and Education Administration and Kansas State University. The research has contributed a considerable volume of information leading to a better understanding of the mechanics of wind erosion and its control. Many of these publications are referenced in this report.

Despite what we have learned from history and research and the help we have had from economic assistance; irrigation and better farm machinery, chemicals and crop varieties the United States still has a significant wind erosion problem. The magnitude of the problem is discussed in the next section.

Magnitude of the Wind Erosion Problem

It is extremely difficult to put a number on the size of the wind erosion problem because it varies with the rigors of the climate, the development of new technology, and government attitude and policy toward crop production. During those years when there is drought the problem is several times more severe than when adequate precipitation occurs and plentiful soil moisture is available. Development of center pivot irrigation is a good example of the effect of new technology. This method of irrigating has enabled large areas of marginal land to be put into crop production, much of which is sandy and extremely susceptible to wind erosion. But on the other hand irrigation results in production of considerably larger quantities of crop residues which can provide protection to the land and thereby reduce the erosion hazard. When the government removes controls and encourages "all-out" or "fencerow to fencerow" production marginal lands are brought into production, shelterbelts may be removed, native grassland may be plowed under and good conservation practices may be neglected all resulting in a larger wind erosion problem.

If we look at the magnitude of the wind erosion problem on a world-wide basis we find, in relative terms, that it occurs on a small scale in the Plains of the United States, in Canada, Australia, Russia, and parts of Central Europe; and it occurs on a large scale in the deserts of North Africa, South America and Mongolia. Geologists estimate that the amount of sediment delivered to the oceans of the world by wind amounts to about 60 to 360 million metric tons per year as compared to 3.8 to 58 billion metric tons per year deposited by water (18). To the geologist then wind erosion compared to water erosion is volumetrically unimportant in delivering sediment to the oceans -- and perhaps it is from a worldwide geological standpoint. However, from the standpoint of their effects on people, environment, crop production and economics especially in the Great Plains, wind erosion and duststorms are extremely important.

According to the Resource Conservation Act Inventory published in 1977 there were 58.1 million acres of crop and rangeland in the 10 Great Plains States with the potential of a wind erosion rate exceeding 5 tons per acre per year. Data were not considered completely accurate for other parts of the United States but roughly it showed another 19.5 million acres also with potential for erosion rates exceeding 5 tons per acre per year located around the Great Lakes in Michigan, Wisconsin and Ohio; along the eastern seaboard; in the Southeastern Coastal areas; and in the Northwest. All of these acres do not actually blow each year because of low velocity winds, timely precipitation and application of special control practices by the land owners. Surveys of acres damaged are not made in all areas of the United States but they have been in the 10 Great Plains States since the 1935-36 blow seasons. These data show acres damaged ranging from one million in the 1942-43 season to 16 million in the 1954-55 season. The average for the 45 years from 1935-36 through 1979-80 is approximately 5 million acres.

Consequences of Wind Erosion and a Comparison with Water Erosion

The consequences of wind erosion are in many respects the same as for water erosion which should be expected because the transport of soil material by wind is a special case of the broader field of the transport of solids by fluids (4). Certain fundamental and relatively great differences exist however between the transport of material by wind in comparison to transport by water. For example, soil, as it is exposed to wind erosion, is composed of solid, liquid, and gaseous components while soil exposed to water erosion is made up principally of solid and liquid components. The greatest fundamental difference between air and water transportation, however, is associated with difference in density of the fluid media.

The most serious damage from wind erosion is the separation and gradual selective removal of silt, clay, and organic matter from surface soils thus reducing the productive capacity of the land. Long term measurements of the effect of this removal on crop production have not been made. However some highly significant estimates have been made using data on the effect on crop yields of artifically removing topsoil and calculations of annual soil loss by wind. Results are shown in Table 1.

These data indicate that about one percent of the wheat yield can be lost due to wind erosion damage and when applied to the 13 southwestern Kansas counties the annual loss on 1.2 million acres of sandy surface soils amounts to 339,000 bushels of wheat and 543,000 bushels of grain sorghum.

It is extremely difficult to separate accurately the effects of wind erosion on crop production from drought. There are data to show that the coefficient of variation for long-term wheat yields in the semi-arid areas ranges from about 37 percent in Canada to 70 percent near Dalhart, Texas, in the heart of the old Dustbowl. The

Table 1 -- Estimated annual reduction in wheat yields from wind erosion under two kinds of residue management.[a]

	WIND ERODIBILITY GROUPS (WEG)[b]					
Location	1	2	3,4,4L	5	6	7
			Wheat residue management			
	- - - - - - - - - - BU/acre/year - - - - - - - - - - -					
Northern Plains	0.45	0.14	0.07	0.04	0.03	0.02
Western Kansas	1.47	0.47	0.25	0.14	0.10	0.07
West Texas	2.52	0.89	0.50	0.28	0.22	0.17
			Grain sorghum residue management			
	- - - - - - - - - - BU/acre/year - - - - - - - - - - -					
Northern Plains	0.88	0.34	0.20	0.11	0.09	0.06
Western Kansas	1.97	0.76	0.44	0.26	0.21	0.15
West Texas	2.89	1.03	0.60	0.35	0.29	0.22

[a] Data from Lyles (19)

[b] WEG indicates relative soil erosiveness ranging from WEG 1 - highly erodible sands to WEG 7 - least erosive silty clay loams.

best estimates of the contribution of wind erosion damage to this variation ranges from zero to a maximum of 10 percent. In Western Kansas, where the main crop is wheat, it is only about 4 percent. Because of this general lack of specific information on wind erosion effects, an alternative is to consider the problem in terms of drought as shown in Figure 1. Two facts are evident from this figure: (1) The three droughts caused a significant reduction in average wheat yield, and (2) the general trend of wheat yields increases over the years thus indicating the influence of better wheat varieties, fertilizer, irrigation, management, etc.

Water erosion also reduces the productive capacity of the land by removing silt, clay and organic matter. Again good data are not available but a study in Georgia showed that loss of each centimeter of topsoil -- equal to about 63 tons per acre -- cost the producer 2.3 bushels per acre of corn yield (20). It has also been estimated that it costs $4 billion per year to replace the nitrogen and phosphorous nutrients lost through water erosion (21).

The consequences of wind erosion are not limited to reduction of the productive capacity of the land. Crops are often damaged or destroyed by the abrasive action of blowing soil. In the Great Plains wheat, sorghum, cotton, sugarbeets, peanuts and soybeans are affected. Other crops and areas affected include: tomatoes, celery, asparagus, green beans, potatoes, carrots, melons and other vegetables in Wisconsin, Michigan, Ohio and New Jersey; and tobacco, corn and vegetables in the Southeast. Sugar beets, potatoes and other vegetable crops suffer extensive damage on new areas brought under irrigation with pivot mobile

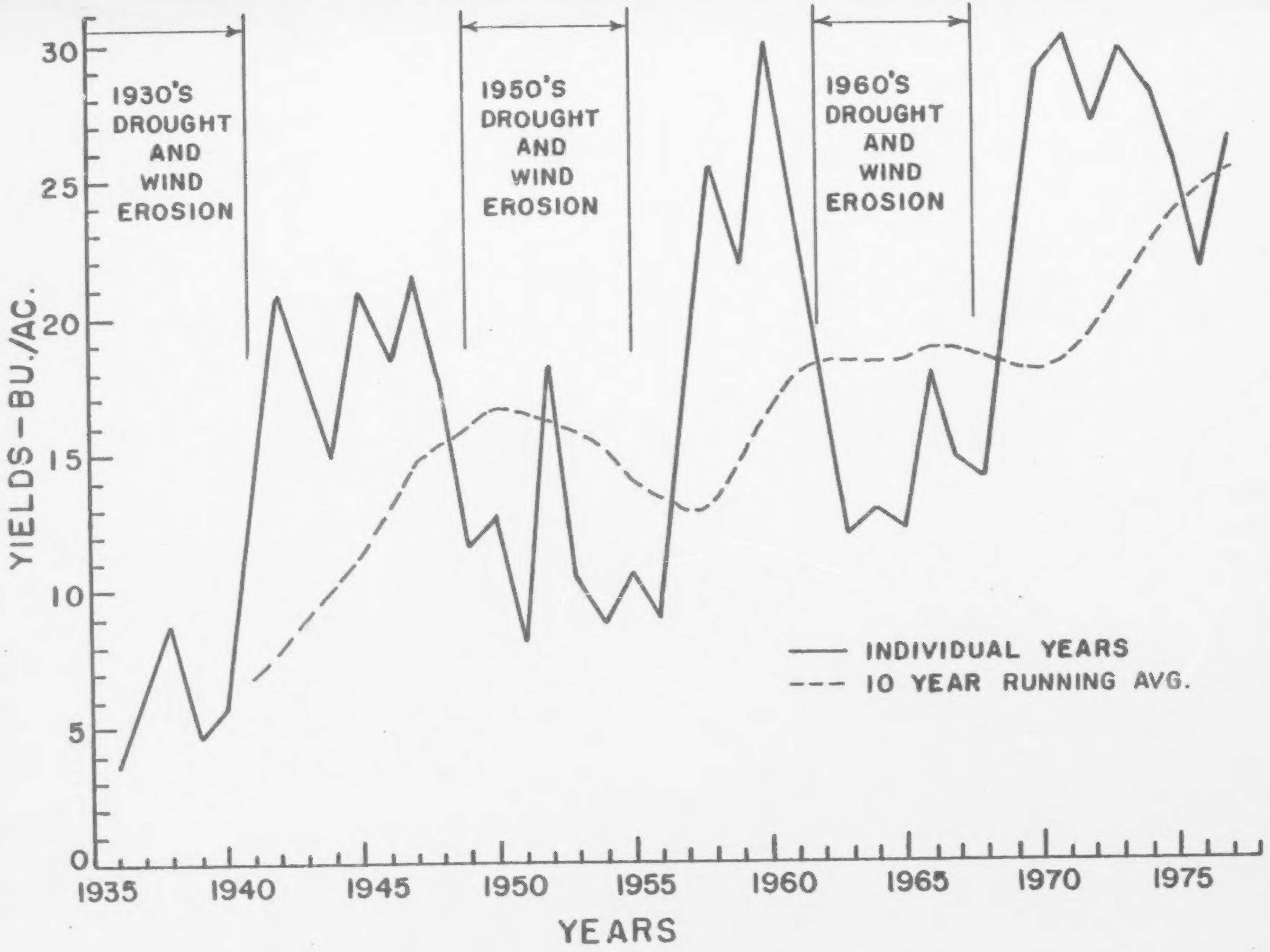
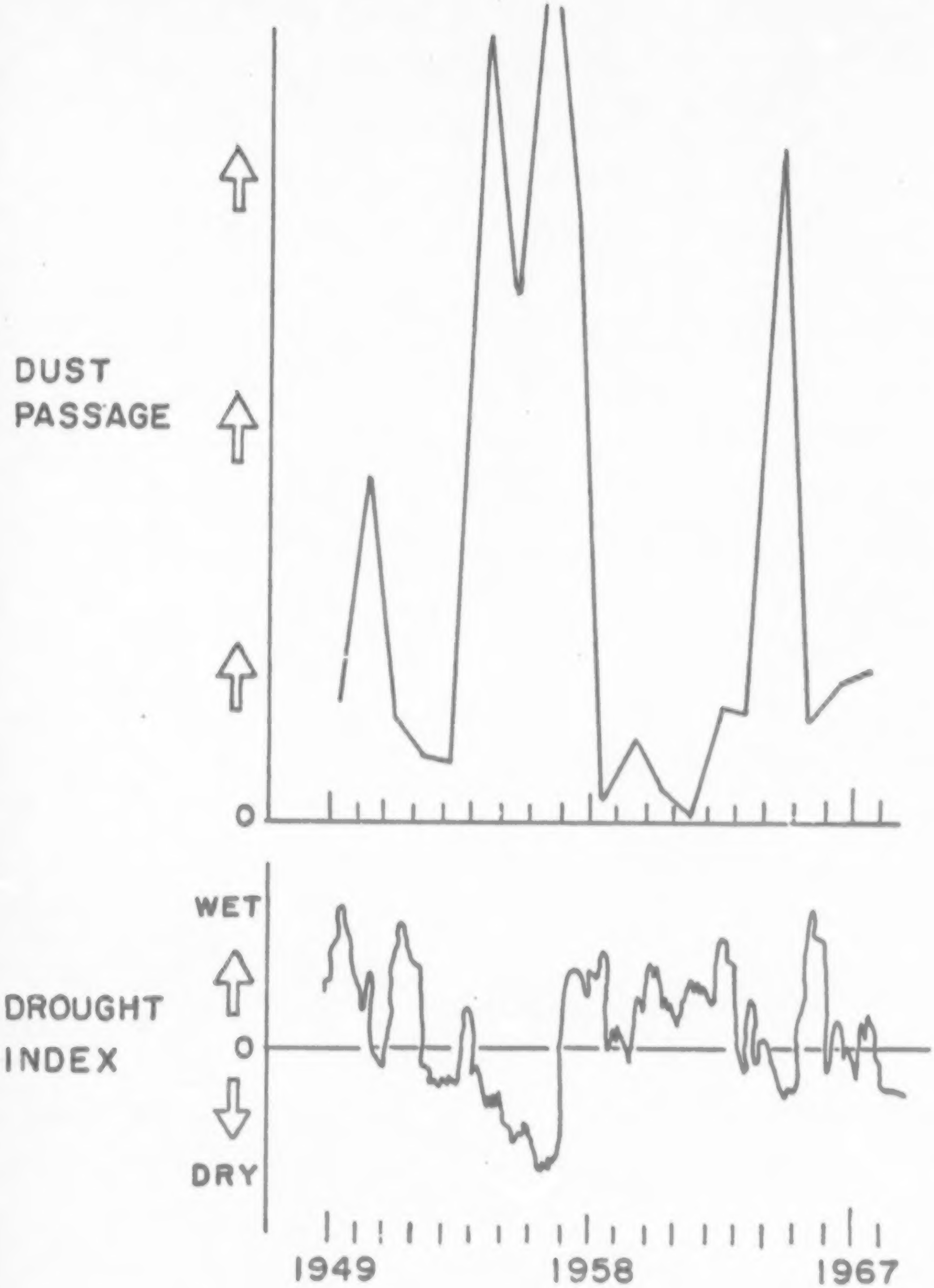


Figure 1 - Effect of drought and wind erosion on wheat yields (Central Great Plains areas of Nebraska, Colorado and Kansas) Source: Greb (22).

overhead sprinklers in the Northwest and in Colorado, Wyoming, Kansas and Nebraska. Estimates have been made that crop losses and replant costs due to abrasion from blowing soil may amount to as much as $50 million per year during years of high climatic stress. Water erosion does not abrade plants but it does "washout" and inundate them often causing severe losses.

Insects and weed seeds spreading for great distances are another consequence of wind erosion. Mounds of windblown soil may smoother grass, shrubs and trees. Drifting soil often buries and ruins fences, hedges, and shelterbelts. Drifted soil and sand sometimes blocks entrances to farmsteads, oil wells, and even city homes.

During duststorms, traffic tie-ups and accidents are common; air transportation is adversely affected and electrical switching stations are commonly damaged. Perhaps the most deleterious effect of wind erosion is from the dust it creates which is both an irritant and health depressant. This pollution of the atmosphere occurs on a small scale nearly every year and becomes severe during drought years (Figure 2). Measurements in duststorms of the 1950's have shown that concentrations ranged from 675 to 280,000 micrograms per cubic meter - far exceeding the 80 micrograms per cubic meter considered tolerable (23). Also analyses of dust data during the decades of the 1950's and 1960's have shown the average duration of duststorms to be 6.5 hours, average area involved to be 188 square miles, and total dust loads in the 1950's to be 244 million tons per year and 77 million tons per year in the 1960's (24). Public concern about environmental quality has generated considerable pressure to develop standards to regulate emission of pollutants into the atmosphere. Iowa and Kansas air pollution emission control standards now



Fgure 2 - Correlation of dust passage and drought index for Northwest Kansas (25).

have regulations that could be applied to set up standards to regulate loss of soil by wind. Other states are working on similar standards. Analyses of atmospheric dustloads during duststorms, such as those cited, indicate that it will be difficult for any state that has a significant wind erosion problem to meet the standards as they are now defined.

Water erosion also transports sediment, about 4 billion tons are washed into tributary streams in the United States each year and about one-fourth of this sediment is transported to the sea (26). Some 30 percent of the water transported sediment delivery arises as geologic erosion such as that found on the tributaries of the Missouri, Colorado, Rio Grande, Red, and Arkansas rivers. This action of carrying sediment from higher to lower elevations is entirely different from wind action which scatters the fine sediment and deposits it in a uniform mantle over extensive areas near and far from the source. Wind is therefore, an agent of soil formation but it is also one of the great destroyers of productive soils.

Factors Affecting Wind Erosion

Major factors that affect the amount of erosion from a given field are vegetative cover, soil cloddiness, surface roughness, windspeed and soil moisture, and distance across an eroding field measured along the wind direction (5).

Vegetative cover, living or dead, is the most important protection against wind erosion, and its removal or depletion by man, animals, insects, disease, or climatic stress has caused wind erosion problems all over the world. Vegetative cover protects the soil surface from wind action by reducing windspeed near the soil surface and by preventing much of the direct wind force from reaching erodible soil particles. It also reduces rates of erosion by trapping soil particles, which, in turn, prevents the normal avalanching of soil material downwind. Protection depends on the quantity and size of residue and how it is oriented in relation to the prevailing wind direction. The finer the residue, the more it slows the wind and the more it reduces wind erosion. Size is largely determined by kind of residue - wheat stubble is more effective than sorghum or cornstubble, for example. The higher the residue stands above the ground, the more it slows the windspeed and lowers the rate of erosion. A selected few of the numerous publications on residues' role in controlling wind erosion are: (3, 5, 27, 28, 29, 30).

Soil clods and aggregates larger than about 0.84 millimeter in diameter prevent wind erosion because they can resist the force of the wind and they shelter other erodible materials. Clods are formed during tillage. Their firmness and stability depend on soil moisture, compaction, microbial activity, and content of organic matter, clay, and lime. Clods are broken down by weathering, tillage, mechanical and animal traffic, and abrasion. Coarse-textured sandy loams and loamy sands are less likely to retain stable clods and therefore are most susceptible to erosion. Selected publications on the role of cloddiness in preventing wind erosion are (3, 5, 31, 32, 33, 34, 35).

Ridges and depressions formed by tillage alter windspeed by absorbing and deflecting part of the winds' energy. Rough surfaces also trap moving soil particles, reducing abrasion and the normal build-up of eroding materials downwind. While the general effect of surface roughness is to reduce wind erosion, it also may increase wind turbulence and expose smaller areas to greater wind force. So too much roughness may substantially reduce the benefits. Optimum roughness for wind erosion control is 2 to 5 inches. Some important publications dealing with roughness' role in controlling wind erosion are (3, 7, 36, 37, 38, 39).

Windspeed and soil moisture both affect wind erosion. For example, the rate of erosion for a 30 mile-per-hour wind is more than three times that for a 20 m.p.h. wind. Wind erosion decreases, however, as soil moisture increases. Completely dried soil erodes about one and a third times more than soil with moisture at about the wilting point for plants. Additional information on windspeed and soil moisture affects on wind erosion will be found in publications (1, 3, 4, 17, 32, 40).

The rate of soil flow on an unprotectected eroding field is zero on the windward edge and increases with distance measured along the wind direction till the rate of flow reaches a maximum that a wind of particular velocity can sustain. Erosive winds vary highly in direction and seldom follow field boundaries. Therefore, the amount of soil lost from a given field cannot be determined by the width or length of field alone. The distance across the field along the direction of the prevailing wind must be used. Also if any barrier is present, such as shelterbelts on the windward side of the field, the distance they fully shelter from the wind must be subtracted from the total distance across the field along the prevailing wind direction. Pertinent publications on this subject include (3, 41, 42, 43, 44, 45).

The results of extensive laboratory and field research on factors influencing wind erosion have been used with analyses of climatic data to develop the wind erosion equation, $E = f(I', K', C', L', V)$, now widely used to determine potential wind erosion on any field under existing conditions and to design wind erosion control practices (41, 44, 46, 47, 48). The equation expresses the relationship between annual soil loss by wind erosion from a given field and the five factors influencing erosion. Variables in the equation are defined as follows:

E is average annual soil loss in tons per acre.

I' is the soil erodibility index indicated by soil aggregates and clods greater than 0.84 millimeters in diameter and percentage of land slope.

C' is the climatic factor indicated by wind velocity and surface soil moisture.

K' is soil surface roughness.

L' is unsheltered field width measured along the direction of the prevailing wind.

V is vegetative cover.

Principles of Wind Erosion Control

Five principles of wind erosion control can be established from analyses of wind erosion phenomena; namely, (a) establish and maintain vegetative or non-vegetative land cover, (b) reduce field lengths along the prevailing wind direction, (c) produce stable clods or aggregates, (d) roughen the land, and (e) level or bench land to reduce effective field widths and erosion rates on slopes and hilltops where wind shear stress maximizes (5, 49).

These principles apply everywhere, but the usefulness of each varies with local climate, soil, and land-use conditions. For example, it is usually difficult to form stable clods on coarse textured soils.

For this reason, control of wind erosion by producing and maintaining clods or by roughening the surface is, at best, temporary. Maintaining vegetative cover is a far better way to control erosion on these soils. Erosive situations may also arise where there is no way of providing vegetative cover. In these situations, emergency tillage should be used to roughen the land surface and produce clods.

Current Control Technology

Wind erosion control practices applied under current technology all utilize one or more of the principles of wind erosion control. In this section we will discuss current technology now being used to follow each of the five principles.

Establish and Maintain Vegetative or Non-vegetative Cover

Establishing and maintaining cover is the "cardinal" or "golden" rule of wind erosion control. Cover is maintained by:

a. Using stubble mulch or minimum tillage practices to prepare land for crop production. Stubble mulching is tillage developed in the Great Plains during the last 20 years and used mostly in wheat and sorghum production. The main purpose of minimum tillage is to grow crops with fewer tillage operations and thus reduce costs of production but a very important secondary purpose is to maintain residue on the soil surface. Developed during the last 15 years in the Midwestern Corn Belt, it is practiced mainly with row crops.

The amount of vegetative residues needed to control wind erosion is related to the five factors affecting wind erosion and can be calculated for a particular situation using the wind erosion equation. Minimum quantities of standing wheat stubble needed under Central Great Plains conditions to hold wind erosion to an acceptable tolerable level of five tons per acre are 750, 1250, and 1750 pounds per acre for silty clay loam, sandy loam, and loamy sand-textured soils respectively. However, the general goal is to maintain as much residue on the land surface in a standing or near-erect condition as is compatible with seed planting procedures.

Tillage machines used for stubble mulching and minimum tillage are of two types: (1) those that stir and mix the soil, and (2) those that cut beneath the surface without stirring or turning the tilled layer. The machines that cut beneath the surface are gnerally preferable over mixing machines for obtaining wind erosion control (5).

The undercutting machines utilize one or more V-shaped or straight rigid blades mounted on a heavy tool bar or frame. The frame may be rigid or flexible to better fit the shape of the land. Blades vary in size from about 30 inches to 7 feet. Major disadvantages of this type of implement are the inability to kill weeds, particularly grassy species under moist soil conditions; and failure to bring clods to the surface for erosion protection.

Examples of machines commonly used that mix the soil are one-way, single, offset, power, and tandem disks; field cultivators, sometimes called duckfoot cultivators; chisel plows; spring and spike-tooth harrows; mulch treaders; and powered rotary tillers. Mulch treaders, despite their mixing action, can provide effective erosion control when used after undercutting tillage because they punch the residue into the soil thereby anchoring it against wind action. Powered rotary tillers, specifically the sidewinder tilther is particularly adapted to row-crop culture and also provides good wind erosion control because it provides intensive tillage to a 12- to 14-inch width of soil for seeding leaving the soil and residue between rows undisturbed.

More residue is conserved for wind erosion control if tillage can be avoided. The ultimate in stubble mulch or minimum tillage is "no-tillage" where crops are planted directly into the residue of the previous crops. This is being increasingly done as effective herbicides for weed control have been developed. The herbicides may be used without any tillage to control weeds or they can be used in combination with limited tillage (50, 51, 52, 53). The word "ecofallow" has been coined for this practice. This method of crop production has considerable appeal in this time of costly energy for tillage and planting. No-till's main disadvantages are that, so far, herbicides have not always proved effective in controlling weeds, herbicide costs are high, there are possible residual carryovers of preemergence herbicides in sandy and high loam soils, and problems are often encountered in planting through heavy undisturbed residues.

Stubble mulch and minimum tillage acceptance and practice continues to grow each year as machine sizes increase and their advantages as a method for both controlling wind erosion and conserving soil moisture become more apparent.

b. Planting cover crops when land is bare between regular crops. A cover crop is any crop planted solely to control erosion. F. H. King recommended planting cover crops for wind erosion control in his bulletin (14) published in 1894 so it is an old practice for controlling wind erosion. Winter and spring wheat, rye, oats, sorghums, winter peas, and vetch are excellent cover crops.

Cover crops are well suited to the more humid areas around the Great Lakes and in Southeastern United States particularly in vegetable growing areas (54). They also have a place in parts of the Northern Great Plains and they are recommended for use on certain soil types in the Prairie Provinces of Canada where they not only provide wind erosion control but also trap snow thus providing additional soil moisture (55). Cover crops are also used on irrigated lands where irrigation water can be used to give quick germination and growth. Cover crops are not as practical in the drier areas of the Central and Southern Plains because they compete for the already limited supply of soil moisture (5). Generally, they are used in these areas only for control on erosion-susceptible knolls, on land without protective cover or on cultivated land to be pastured. However, one practical method of skirting the moisture depletion problem is to plant crops which provide some growth than winter kill leaving plant residue for protection but no longer requiring water. Similar results can also be obtained by using a herbicide to kill a crop after it has provided some protective growth.

While there is some evidence in the cornbelt states that a common practice of planting oats after corn harvest to protect the soil from blowing and at the same time provide cattle feed is being abandoned because of the high cost of labor in today's economy, it is believed that use of cover crops as a means of controlling wind erosion will continue at about the present level.

c. Using crop rotations in which two or more crops or one crop and fallow are alternated on a given area in a regular sequence. This prevents leaving large blocks of land bare during the wind erosion season. Common rotations in wind erosion areas include: wheat-fallow, wheat-sorghum-fallow, and cotton-sorghum (22, 51, 56, 57).

Rotating crops is a practice nearly as old as modern agriculture. Generally it was advocated primarily for improving soil tilth and productivity rather than for erosion control. This was especially true when legumes and grasses were included in the rotation. However the practice does provide chances for better year around cover for erosion control than does single cropping. The practice probably will not be used as much in the future as in the past because of the desire for large blocks of land to accomodate large machinery and the ability now to provide plant nutrients with commercial fertilizers.

d. Controlling grazing of both rangeland and winter wheat to prevent complete denuding of vegetation and pulverization of the surface soil. It is a common practice in the Great Plains to pasture winter wheat during those years when sufficient soil moisture is available to produce abundant fall and winter growth. Usually this is an economically advantageous practice for the farmer and does not affect the yield potential of the crop; however grazing must be controlled so that complete denudation does not occur. Control on range grazing lands is attained by: (1) limiting livestock numbers on any given area, (2) providing reserves of harvested forage for use during drought periods, (3) dividing pastures and using rotational grazing, (4) supplying several watering and salt box sites and moving boxes from time to time, (5) fencing animals away from highly erosive areas, and (6) applying hauled-in mulches, brush, and automobile tires to blowout spots (5).

This method of controlling wind erosion has been used for a long time and should continue to be practiced at about the same level in the future.

e. Regrassing and reforesting areas such as sand dunes, blowouts, mine slag and slime dumps, and other unproductive land to prevent air pollution and spread of wind erosion to more productive land. Reclamation and control methods are often determined by economics but the goal in all cases is to establish permanent vegetation. Usually the first procedure in gaining control requires some bulldozing and land farming then seeds and/or culms or stems of adapted grasses and trees and shrubs can be planted, preferably with mulch, adhesive soil stabilizers, or other protective material (5).

   This method of control has been practiced, at least on a limited scale particularily on sand dunes along coastal areas to protect summer beach cottages and military installations for the past 40 to 50 years. It is expected to be utilized more extensively in these areas and in mine slag dumps in the future as we are more concerned about air pollution and more coal is surface mined.

f. Applying hauled-in mulches or non-vegetative and processed covers to areas of severe wind erosion or to areas with high economic return potential. Costs prohibit widespread application of this method of erosion control to large dryland agricultural areas such as the Great Plains. However it is applicable to dune stabilization, providing erosion control on vegetable and speciality crop lands, and to "blow out" or "hot spot" erosion problems in the large dryland agricultural areas such as the Great Plains.

Vegetative mulches commonly used include cotton gin trash applied at 1 to 2 tons per acre, corncobs applied at 4 to 5 tons per acre, and manure applied at 15 to 30 tons per acre (5, 58). Straw and hay mulches must be applied with an adhesive such as asphalt or be anchored with disk packers (59).

Several spray-on adhesives of petroleum, chemical, and organic origin are available for use as temporary covers for wind erosion control (60, 61). They are expensive and their use has been limited to protection of vegetable and speciality crops and to stabilization of dunes surrounding military landing strips and missile sites. A list of 5 of the most economical adhesives and their dilution and application rates is:

Stabilizer	Water Dilution	Application Rate Gals/Ac.
Asphalt emulsion	7:1	1200
Latex emulsion	12.5:1	235
Resin-in-water emulsion	4:1	300
Liquid protein colloid	10:1	440
Fermented corn extract	10:1	570

Use of this method of wind erosion control received considerable attention in the late 1960's and early 1970's before the world-wide petroleum shortage existed. Their use declines as prices have increased and they are now mostly used only on a limited scale on very highly erosive situations where there is potential for high economic return or where disastrous consequences may result if erosion is not controlled, e.g. to stop air pollution from blowing toxic mine materials or along interstate highways where blowing soil could cause automobile accidents.

Reduce Field Widths Along the Prevailing Wind Direction.

Since, as we have already indicated, wind erosion is an avalanching process with an increasing rate of soil flow across an eroding field it follows that any measure that reduces field length along the prevailing wind direction will reduce erosion. Field widths are reduced by:

a. Using stripcropping where strips of erosion resistant crops are alternated with strips of erosion susceptible crops. Erosion resistant crops are small grains and other crops that rapidly produce a cover. Erosion susceptible crops include corn, cotton, tobacco, sugar beets, peas, beans, peanuts and most truck crops. In the Great Plains, alternate strips of wheat and grain sorghum, or fallow wheat stubble and newly seeded wheat, are used. Permanent strips of tall perennial grasses are also planted on fallow wheat land to reduce erosion (62). In vegetable growing areas, alternate strips of rye and vegetables are commonly planted (54).

   Stripcrops are run at right angles to the prevailing winds. The actual width of strips needed to control wind erosion varies with topographic features such as irregularity; length, degree, and exposure of slope in relation to prevailing winds; and with factors affecting field erodibility;

e.g. soil texture, cloddiness, roughness, and wind velocity and direction (3). The strips may range in width from a single row of grain sorghum or corn when used in vegetable crop applications and from 20 feet on sandy soils to 430 feet on silty clay loams in the wheat growing areas of the central Great Plains. Exact widths for different situations can be calculated with the wind erosion equation.

Stripcropping has been used in the Plains since the Dustbowl days. Disadvantages of stripcropping are smaller fields requiring traveling from strip to strip, and increased insect problems because cover is provided by fallow strips or other crops which may be different from the current production crop. The ever increasing size of farm machinery has also made stripcropping objectionable to some farmers.

b. Using windbreaks and shelterbelts to reduce field widths and lower windspeeds (63). Their ability to ameliorate climate and to provide erosion control has been recognized for a long time. Shelterbelts have been used in China for many generations to protect sandy land from erosion by wind (64). There is evidence that they were used in Scotland as far back as the 15th century (65). They have been used in the United States for well over a century with early research being conducted by King (14) in 1894 and Carlos Bates (66) in 1911. Their use in the United States received great impetus between 1935 and 1942 following the drought and dustbowl when President Franklin Roosevelt was successful in implementing the Prairie States Forestry Project which used WPA labor to plant field windbreaks in a 100 mile wide strip roughly paralleling the 100th meridian from Texas to the Dakotas (67). These shelterbelts were generally wide -- consisting of 10 to 12 rows. Subsequent research has shown that shelterbelts need not be this wide to provide effective wind erosion control and more recent plantings have generally been composed of 1 to 5 rows of deciduous and coniferous trees. Narrow rows of tall growing field crops, snowfences, solid wooden and rock walls, and earthen banks also have been used for windbreaks.

The effectiveness of any barrier depends on the wind velocity and direction, and on shape, width, height, and porosity of the barriers (5, 68, 69, 70). The speed of the wind blowing at right angles to the average tree shelterbelt is reduced 70 to 80 percent near the belt, about 20 percent at a distance 20 times the height of the belt, and only about 2 to 5 percent at a distance 30 times the height of the belt (5).

Most barriers used for wind erosion control can be expected to provide protection for distances ranging from 1 to 18 times their height, depending on type used. These relatively short distances require close spacing, which reduces field size and objectionable where large farming equipment or mobile center pivot irrigation systems are used. For this reason, tree shelterbelts are usually planted at about 80 rod intervals along field boundaries, at 350 to 450-foot intervals on highly erosive soils or 500 to 650-foot intervals on moderately erosive soils. Other wind erosion control practices, such as stubble mulching are then applied to the land as supplemental control.

Nearly any plant that reaches substantial height and retains its lower leaves has been used as an annual crop or grass barrier. These include pampas, tall wheat, plains bristle grass; hybrid forage sorghum, kenaf, corn, and sunflower. Spacing between annual crop or grass barriers ranges from 10 to 60 feet, depending on soil texture, control required and other factors.

Artifical barriers such as snow fencing, board walls and earthen banks provide temporary protection for highly erodible areas such as livestock watering sites and traffic lanes. They have also been used to protect high-value crops and to stabilize sand dunes. They provide a relatively short zone of protection; a 4-foot high snowfence protects for a distance of about 40 feet, and a 2-foot high earthen bank protects for about 30 feet. Artifical barriers are costly to construct and therefore have limited application.

Planted tree windbreaks have most application on sandy soils and in areas where there is substantial rainfall. They do not do well in the drier climate like on the western edge of the Great Plains where annual precipitation is less than 20 inches per year.

Today the use of windbreaks for controlling wind erosion is declining. This decline is primarily due to the interference they cause to farming operations using the large modern machines. Also it is due to use of center pivot irrigation systems which must have large open areas in which to operate. Perhaps it is also due to the fact that over the years there has been no substantial evidence to discredit the opinion that shelterbelts cause declines in crop yields. Theoretically, since the shelterbelt can trap snow and can ameliorate climate it should provide additional water and a better environment for crop production. There is some evidence of increased yields out to about 10H in some situations (69). However the trees also require water and very often there is no real increase in yield. Because of all these reasons many of the shelterbelts planted in the 1930's have been bulldozed out and fewer new shelterbelts than in the past are planted.

Produce Soil Clods or Aggregates and Roughen the Land

Since soil cloddiness and land roughness depend to a large extent on methods of regular tillage and planting used in producing a crop; the practical application of these two principles of wind erosion control require prior planning and are therefore difficult to apply in an emergency situation brought on by sudden climatic stress. Optimum roughness for controlling wind erosion is 2 to 5 inches. The degree of cloddiness needed to prevent erosion depends on soil texture, climatic condition, amount of available vegetation, etc; but in general land with 50% of the surface soil consisting of clods greater than 0.4 inches in diameter will not blow (35, 44, 71).

During regular tillage and planting operations for crop production the soil will be rougher if minimum or stubble mulch tillage practices are used. Special planters such as the till planter for row crops and the deep furrow or hoe drill for small grains also produce a roughness in the most effective range.

With tillage implements commonly used in stubble mulching the most cloddiness is produced by 2-inch chisels and 32-inch V-sweeps, followed in order by disks, rodweeders with shovels, and large V-sweeps (72). Deep plowing of sandy soils to depths of 3 to 4 feet, a practice used extensively in the early 1960's can also be an effective way to provide soil cloddiness if there is a reachable subsoil layer with at least 27 percent clay content (73).

Emergency or "last resort" tillage is a method of producing roughness and cloddiness on both cropped and fallow land which has been practiced since the 1930's when vegetative cover is depleted and climatic stress situations arise and fields begin blowing (5). It can be accomplished with a number of common tillage implements including chisels, listers, field cultivators, etc. The lister is probably the most effective but it is a drastic method of tillage which destroys any crop e.g. winter wheat which might still have a chance to produce a crop. Chisels, if tool shanks are spaced 3 to 5 feet apart can stop soil blowing and save much of the growing crop. For most effectiveness, emergency tillage should be accomplished before soil blowing begins; however if blowing has started then the operation is begun on the windward edge of the field.

Surface roughening and maintaining soil cloddiness are wind erosion control practices which the farmer may tend to forget in years of good rainfall and low incidence of wind erosion; however, they often become very important in bad years. Use of the practices therefore varies, but generally the increased use of stubble mulch and minimum tillage has provided a rather high level of application of these principles. Emergency tillage is still an important tool for stopping soil blowing. Deep plowing, however, is not practiced to any great extent today mostly because the efforts in the 1960's showed the benefits to be short lived and it is a high energy consuming operation making it extremely costly at today's petroleum prices.

Level or Bench Land

Land is often leveled or benched for purposes of irrigation, water erosion control, and moisture conservation. These land modifications affect the rate and amount of wind erosion because field lengths are shortened and erosion forces may be reduced or increased on slopes and hilltops.

Quantitative information on the relationship between land modification and wind erosion is meager. However estimates using the wind erosion equation indicate that shortening field lengths from 1000 to 100 feet by benching reduces the wind erosion potential by 50 percent. It is also known that when wind flows up long slopes the streamlines of flow are compressed indicating steeper velocity gradients, and therefore greater shear stress than occurs over level terrain. For example, on a 4 percent slope the soil loss is about 1.6 times greater than from the same field if it were on level land (71, 74). It can also be shown that if this slope is benched with a series of 240-foot wide level benches, the soil loss from wind erosion would be reduced about 60 percent.

It is unlikely that land will be extensively modified to control wind erosion, but it is being increasingly modified for irrigation, moisture conservation, and water erosion control. These modifications will also provide substantial wind erosion control.

Potential for Modifying Current Technology and Possibilities for New Technology

Any discussion of the potential for modifying current technology and the possibilities of developing new technology to control wind erosion must keep in mind: (1) the relative importance of the wind erosion problem in relation to other problems of agriculture, (2) the relation of the problem to other agricultural problems, and (3) the study, research and contention that man has applied and experienced to and with the problem during the past 50 years.

In this report we have indicated sediment transport by wind to amount to from 77 to 244 million tons per year but we have said that water erosion moves 4 billion tons of sediment per year. If simple ratios of water erosion/wind erosion are used we obtain numbers of either 16:1 or 52:1. If these ratios are interpreted as indicating the seriousness of one problem as compared to another then we must conclude that water erosion is a much larger problem. Similar comparisons could also be made comparing damages caused by wind erosion with those caused by drought.

We have also indicated in this report that wind erosion does not occur unless the soil is dry, pulverized and loose. These conditions are brought about by lack of precipitation and high temperatures i.e. drought. Therefore we can conclude that we would not have a wind erosion problem if we did not have drought and we can further extrapolate this conclusion to say that drought is a more serious problem than wind erosion.

Man has studied, researched, and contended with the wind erosion problem for 50 years and more. During this time he has developed and tried many ways of controlling wind erosion. He has developed principles of control and ways of applying their principles and it seems very probably that he has exhausted his reserve of new ideas.

All of this is not to say that wind erosion is not a serious and important problem. We have pointed out the damage it can do to the future productivity of the land, the effects on the environment, and the economic losses it can cause. Rather it is to point out the importance of keeping the big picture in mind, to help us realize that more of our limited resources may need to be applied to other problems, and to indicate to us that we may do a better job of controlling wind erosion in the future more because of new technology in related areas than in wind erosion control alone.

Potential for Modifying Current Technology

It seems reasonable to expect that the five principles of wind erosion control will continue to be applicable in the future but potential for modifying current control technology appears to be limited to the following areas.

--The best bet for improving control technology lies in improvements of the stubble-mulch-no till-ecofallow system of tillage. Improvements in chemicals making them both more effective in controlling weeds and less toxic to the coming crop due to residual carry over could result in greater acceptance of their use and therefore provide protection to thousands of acres of land not now protected. New design of subsurface sweep tillage to incorporate vibratory or dynamic action to the blades' movement through the soil could increase weed kill and production of cloddiness on the soil surface to prevent wind erosion. Similarly improvements in design of planting equipment to provide easier more efficient planting in heavy residues could result in greater acceptance of the stubble mulch-no till-ecofallow systems and protect more acres from wind erosion.

--Cover crops could provide greater wind erosion control if technology for pelleting and capsulation are developed to supply seeds with water and nutrients to insure quick germination and therefore quick cover to protect the land.

--Development of new products and further research and testing of present petroleum and chemical spray-on adhesives could improve this area of control technology if it can be done to provide control at a reasonable cost under present economics for these products.

--Despite the decline in use and even the removal of shelterbelts it is believed that some basic aerodynamic research by engineers to determine optimum porosity of narrow windbreak and some concentrated efforts by foresters to select and develop more hardy adaptable tree and shrub species for use in narrow windbreaks could revive farmer interest in utilizing this method of controlling wind erosion.

--The effectiveness of emergency or "last resort" tillage in controlling wind erosion could be improved by study and research which would provide guidelines to the effectiveness of different implements and criteria for determining the production potential of a winter wheat crop after it has been emergency tilled to prevent soil blowing. Also development and design of new machines capable of forming clods through compaction and then stabilizing them with an adhesive before spreading them back on the land surface could greatly improve wind erosion control.

--Effectiveness of land modification techniques can be improved by additional investigation of the influence of topography on wind erosion and the development of design criteria for benching or otherwise modifying topography.

New Technology

Development of new purely mechanical and practical technology for controlling wind erosion is likely to be extremely limited; however development of new technology in a couple of purely mechanical control methods and in several areas closely related to wind erosion could considerably enhance control.

--Development of methods of preserving crop residues available for wind erosion control by exercising control over microbial activity, which causes rapid decay of residues, and treating them with petrochemicals similar to wood preservatives could provide improved wind erosion control.

--Research including economic analyses to establish sandblast tolerances for high economic return vegetable crops and quick and easy tests, e.g. like cold hardiness tests for use in assessment of plant damage and prediction of yield and economic return could reduce economic losses growers now suffer due to wind blown soil sandblasting.

--Development of more precise data on wind erosion's impact on long-term soil productivity, and quantification of erosion standards for reporting severity of erosion would improve wind erosion control simply because it would provide believeable information for use in convincing farmers of the urgency for wind erosion control to maintain soil productivity. Now we do not have hard evidence of these facts and it is difficult to convince a farmer that he should spend money for control practices when he can look at long term wheat yields, for example, and see that the general trend, despite wind erosion and drought damage, is increasing yield since the 1930's.

--Research in the human behavioral area is needed to learn more about farmer perception of the wind erosion hazard and why there is resistance to application of proven control practices and why he is willing to gamble on the probability of a serious wind erosion occurrence rather than routinely apply short-term or permanent control measures. The Thematic Apperception Test with interpretation by the Shaw-Henry Technique could be used (75, 76, 77). Similar investigations of drought have revealed the startling information that only 25% of the farmers saw a need to do anything, some prayed for rain, but most simply exhibited tenacity and stoicism rather than a desire to find solutions. A better understanding of behavior attitudes in the wind erosion control area could lead to finding better ways to approach, educate, and encourage farmers to apply control proactices.

--New technology in the area of predicting and forecasting wind erosion activity could greatly improve our ability to cope with the problem. Prior planning is needed to provide effective control; therefore if we were able to predict an occurrence of erosion sometime in advance of the actual event better control could be obtained. The basic wind erosion equation would be involved but it must have probability functions incorporated for the present dynamic variables and thus convert it from its present deterministic to a stochastic model. Remote sensing supported with good ground truth would also be needed.

--Development of integrated or complete farming systems could greatly facilitate control of wind erosion. Now we fail to realize that wind erosion control is part of a whole, i.e. control techniques must be integrated with soil and water management; capital requirements; machinery, fertilizer and weed and insect control needs; and suitable plant variety selections (78). A team of experts from each of these fields working in a facility called a "Center for Analyses of Farming Systems" would probably be needed to realize this goal.

--Continued efforts in weather modification has potential for reducing the wind erosion problem especially that aimed directly at preventing drought by enhancing precipitation. This technology is presently beset with technical problems concerning cloud seeding technology, funding, cost benefit assurances, and legal and social aspects but if these problems can be resolved and precipitation can be enhanced then the wind erosion problem can be reduced (79).

--Improvement in irrigation technology and perhaps more importantly assuring a continued supply of irrigation water in the Great Plains can improve wind erosion control. This report has previously mentioned the importance of irrigation in reducing wind erosion. Almost 20 million acres are irrigated on the Great Plains with water pumped from the aquifer. However water tables throughout the Great Plains are being depleted at an alarming rate (80). Should this trend continue and it became necessary to return to dryland farming wind erosion problems would increase many fold. Efforts are needed to find ways of reducing seepage, evaporation, and transpiration losses. Inconsistent water laws, regulations, and policies administered by Federal, State and local institutions must be replaced with workable ones. Again, most importantly new sources of water must be found.

The Role of Regulatory, Legislative, and Institutional Mechanism

Regulatory, legislative, and institutional mechanisms have and will no doubt continue to play important roles in both facilitating and inhibiting our ability to control and repair wind erosion. Not surprisingly some of the mechanisms that inhibit our ability to control wind erosion are the same ones that facilitate control, e.g. funding and lack thereof. Some specific examples of inhibiting and facilitating mechanisms follow.

Mechanisms that Inhibit Control and Repair of Wind Erosion

Inflation--In today's economy farmers must make investments on the expectation of inflation rather than on any calculation of the most efficient mix of input to output or on any basis of effective erosion control practices (81). Income tax laws which allow them to write off interest payments encourage them to take high financial risks. They buy both equipment and land, utilize both intensively with little attention to protecting the land and expect inflation to sustain them and the markets because they cannot produce enough at present costs and prices to make a profit. Erosion control practices are luxuries they can ill afford.

Cost of Modern Farming --Very closely tied to inflation is the cost of farm equipment. It is estimated that $200,000 is required for farm equipment alone to start up a dryland wheat farm (81). Because of this the farmer must maximize cash income and he must put his efforts where they will earn the most money. Therefore land is cultivated intensively, abandoning conservation practices.

Demand for Agricultural Products -- Several factors have caused increased demand for agricultural products thereby causing more marginal land to be brought under production and more intensive utilization or "fence row to fence row" farming of all land with less attention to erosion control. There are: (1) Increased per capita income in both developed and underdeveloped countries making it possible to buy more and better food, (2) Increased world population, (3) Food and feed grain exports to the communist countries, and (4) need for foreign exchange to purchase oil, vehicles, textiles, etc. (82).

Federal Relief and Rehabilitation Programs -- There is evidence of questionable procedure in dispensing assistance under these programs (79). It is done only after a Presidential declaration and therefore is to some extent political. The relief and rehabilitation funds provided therefore have opportunity to perpetuate continued attempts at farming marginal lands with high erosion susceptibility and discourage any attempt to apply control practices.

Declining Capital Support of Soil Conservation Programs -- Capital support of these programs has declined substantially since 1970 (82). This deficiency has occurred in funding of: (1) Wind erosion research programs and in allied education and action agency programs needed to get control practices on the land, (2) Long term land use alternative study programs, (3) Weather modification programs, (4) Weather and climate research and analyses programs and their affiliates needed to disseminate weather information to the farmer for use in strategic planning and (5) Plant genetic research programs designed to develop drought and erosion resistant - high yield crops.

Misguided Technical Assistance Efforts by Federal and State Agencies -- There is some evidence that technicians charged with assisting farmers, and scientists charged with developing new erosion control technology may spend too much time in preparation of elaborate engineering plans for a farm, and too much time on basic academic research; and not enough time in developing and assisting in applying simple common sense control measures.

Complacency of General Public -- This is really not an inhibiting factor due to legislative, regulatory or institutional mechanisms but there is a very definite need for these agencies to become more involved in bringing the need and urgency of applying erosion control practices to the land to the Public's attention.

Mechanisms That Facilitate Control and Repair of Wind Erosion -- Regulatory, legislative, and institutional mechanisms which have facilitated control of wind erosion include: (1) The support provided for research agencies i.e. USDA-SEA and Land Grant University Agricultural Experiment Stations, (2) The support of action agency programs i.e. USDA-SCS and University Extension Services, (3) The Relief and Rehabilitation Programs, (4) Quasi land use regulation programs such as the Soil Bank and Conservation Reserve, (5) Water Pollution Control Act Amendments (P.L. 92-500), (6) Great Plains Program and the Aricultural Conservation Program, (7) The Federal Crop Insurance Corporation, (8) Production Credit Associations and (9) The Resource Conservation Act (RCA).

These programs have facilitated wind erosion control because they have: (1) provided technical assistance to farmers, (2) provided financial support in form of insurance to smooth out climate induced variability of income, (3) provided credit when sources are limited and the borrower is risky, (4) purchased and retired or made contracts with farmers to get marginal highly erosive land out of production, (5) promoted installation of best management practices (BMP's) and (6) provided support for inventorying land resources and problems.

What Congress Can Do To Improve Use of Erosion Control Practices

The Congress can assist in improving the general use of conservation practices to minimize soil erosion by providing funds, establishing policy, providing leadership, and creating organizations and vehicles for study and investigation of existing and potential problems. Some specific examples follow.

--Funding for appropriate long-term land use alternative studies should be provided. The National Agricultural Lands Study (NALS) authorized in 1979 is an excellent beginning to this problem. In the interests of better erosion control, it should be followed up with further study and analyses to define alternate uses of land in relation to periodic climatic stresses as well as in relation to conversion of land to non-agricultural uses.

--Funding should be provided for plant genetics research now in progress in many places in the world to develop drought resistant-high yielding crop varieties. This research is of great importance not only in providing erosion control but also to world food production.

--Funding for wind erosion control research should be moderately increased. At the present time only about 6.5 scientific man-years are devoted specifically to wind erosion research. The research should be directed not to basic erosion mechanics but to damage assessment, erosion quantification, prediction and forecasting, and development of simple, practical erosion control practices. The probability for success in these and other areas of research previously mentioned in this report has been estimated at 70% but the probability of achieving this with present funding and staffing within the next 10 years is not more than 50%. No new laboratories or research facilities are needed but funds ought to be increased to provide 4 to 6 additional scientists and their support.

--Funding for applying and maintaining conservation programs on the land must be continued and increased. For reasons stated previously in this report it has become increasingly evident that the farmer cannot be expected to finance conservation programs. One investigation showed that to control wind and water erosion to a tolerable 5 tons per acre per year would cost 3 times more than the benefits derived (83). Yet we must protect our land natural resource. This effort must be supported with public funds.

--Leadership and an organizational mechanism to examine present procedures for dispensing financial relief in times of climatic stress should be provided to make sure that political influence does not result in a perpetuation of continued farming of marginal highly erosive lands that can easily initiate erosion which will spread to productive lands.

--Leadership and possibly new more definitve laws need to be provided outlining responsibilities and limitations for weather modification so that this potential for reducing wind erosion can be more fully developed. Closely related to this need is another concerned with eliminating deficiencies now existing in dissimenation of weather and climatic data to farmers so they can make better strategic and tactical decisions concerning food production and erosion control. Better funding and new guidelines need to be provided to Federal and State Cooperative Extension Services. These organizations need meteorology specialists on their staffs to assist farmers in making use of weather information in planning strategies concerning crop varieties, size of irrigation system, etc. (84).

--Continued support of efforts to find ways of solving the problem of diminishing ground water supplies on the Great Plains must be provided. Serious affects of this drawdown can be expected within the next 30 to 60 years. Leadership and support must be continued for efforts like the long range study of the Ogalla Basin Aquifer. The program to study feasibility of importing water from the Missouri River needs to be continued with greater emphasis. Another look, in cooperation with Canada, needs to be taken at the North American Water and Power Alliance (NAWAPA) proposed in 1964 which would divert 36 trillion gallons of water from Alaska and Northern Canada to 33 states in the U.S., 7 Canadian Provinces, and 3 states in Mexico (85). The words "grandiose," "foolish" and worse were applied when it was proposed but the prospect of the fertile soil resource of the Great Plains - the Nation's "bread basket" reverting to dryland argiculture with all the hazards of the 1930's is bleak indeed. In this day of large populations and great demand for food we must consider all alternatives for obtaining water.

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Background Paper No. 35

CALIFORNIA ANNUAL GRASSLANDS

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U.S. Congress

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CALIFORNIA ANNUAL GRASSLANDS

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Abstract

1. Description. The California annual grasslands represent the only major range type in the western United States in a true Mediterranean climate. The California grasslands are also the only major range type dominated by annual grass species. The grasslands support a wide variety and diversity of native and introduced species in a multitude of habitats.

2. History. Use of the rangelands of California for grazing domestic livestock dates from the arrival of the first Spanish in 1769. Through Spanish and Mexican mission days the livestock industry expanded until great herds of cattle, sheep, and horses utilized the grasslands. The gold rush brought thousands of Americans to the new state and created a demand for red meat. Severe droughts, declining markets, and the growth of farming ended the open range livestock industry in the 1860's. All these practices have resulted in the conversion of the pristine California perennial grasslands to an alien annual grass dominated vegetation. This irreversible conversion is the only example of this process among major range types in the United States.

3. Productivity. The California annual grasslands produce green forage during the fall, winter, and spring and are dry during the summer drought. With an estimated carrying capacity of 1.07 AUM's/acre (2.7 per ha) the California grasslands are among the most productive in the western United States.

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4. Impact of nongrazing uses on rangeland productivity. With its abundance of mountains and ocean beaches California offers many recreation sites more desirable than the annual grasslands. However, during late winter and early spring when the grasslands are emerald green and blazing with a succession of wild flowers the grasslands are very desirable and appreciated environment. Hunting of quail in the foothills and blacktailed deer in the north coast are important recreational activities. Off-highway-vehicles are a problem in local areas.

5. Peripheral activities influencing range productivity. There is probably less conflict between livestock and wildlife on the annual grasslands than with most other range resources. There are few or no free roaming horses. Stock water development benefits wildlife.

6. Technologies influencing range productivity. Range managers have a great deal of research material available for use in making decisions on management of California annual rangelands. Basic ecological information has been developed to document successional changes. Techniques for range improvement through seeding annual legumes are available.

7. Potential reductions in productivity. One of the greatest dangers to the productivity of annual rangelands is the accidental introduction of a new noxious species. The current annual rangelands are probably more productive in quantity and quality of forage than the pristine perennial grasslands. However, the annual communities are susceptible to new introductions of noxious species.

8. Scientific knowledge and data base. Sufficient knowledge is available for decision makers to be able to predict most of the consequences of their actions.

9. Government policies that influence the technologies used on the regions range resources. Lack of a clear directive on improvement and management of these lands by a State Agency. Putting all rangelands under jurisdiction of California State Division of Forestry may be responsible for lack of attention to needs of important rangelands in the State. Reviewers expressed most concern with the following laws and regulations: a) state and federal restrictions on use of herbicides; b) water quality control especially Public Law 208, on point source pollution; c) state and federal predator control programs; d) tax assessment policies on range improvements; and e) forest practice regulations.

Introduction

It is difficult to picture California with its image of intensive agriculture, freeways, and large cities as a range livestock area, but the California annual grasslands are an extensive and highly productive range type which supports an estimated 7 million AUM's (animal unit months) of grazing annually (Forest Service 1972). In sharp contrast to other far western rangelands only about 10% of total AUM's comes from federally and state owned rangeland. The California annual range is almost entirely privately owned. With an estimated carrying capacity of 1.07 AUM/acre the California annual rangelands are very productive in comparison to other rangelands.

California is also unique among western states in being deficient in beef production, having to import large amounts of beef from neighboring states to feed its population. The most unique thing about the California annual ranges is the Mediterranean climate that supports annual grasslands. Summers are hot and usually dry. The annuals germinate with the first effective fall rain, which usually occurs in mid to late October. Limited growth occurs during the winter. During the late winter and spring the annuals usually produce an abundance of herbage. When soil moisture is exhausted after the rains stop in late April or early May the annuals produce seed and remain dry until the rains initiate germination the next fall. The true Mediterranean climate is rare in the United States, but worldwide it is a very important range type occurring in Australia, Chile, and South Africa besides the Mediterranean basin.

At the risk of overusing the superlative we must also mention the uniqueness of the California annual grasslands in being one of the few vegetative formations in the United States where the original vegetation has been nearly completely changed from perennial to annual grass dominance.

Distribution

The original valley grasslands covered well drained areas from sea level to approximately 1200 m in all the mountains surrounding the great central valleys. The grasslands occurred in scattered patches throughout the coast ranges, with the possible exception of the narrow fringe of coastal-facing slopes from Santa Cruz northward (Heady 1977).

Almost completely enclosed by mountains the Sacramento and San Joaquin Valleys of California are one of the most notable structural depressions in the world (Bailey 1966). The Great Valley of California is more than 640 kilometers long and averages 80 kilometers wide. Most of the valley lies close to sea level in elevation, but along the margins in places it rises somewhat higher. The maximum being 520 m at the top of steep alluvial fans which rest against the mountains at the southern end. The basin has a single outlet, Carquinez Strait, crossing a section of the coast ranges through which the Sacramento River flows into San Francisco Bay.

The pristine California grassland appears to have been little different in distribution from the present day grassland, except the areas taken for cultivation. Boundaries with woodlands and chaparral may be less or more distinct because of European man's activities, but it is doubtful that their relative locations have been changed (Heady 1977). The margins of the California grasslands are often somewhat indefinite because the grasslands form the understory and seral dominant of numerous oak (Quercus) woodland communities in the foothills around the margins of the Great Valley (Griffin 1977).

Soils

California grasslands occupy a variety of topoedaphic situations in the complex of physiography and climate which influences the Mediterranean ecosystems of California. There is no modern summary published of California grassland soils despite the fact that the state prides itself in undertaking a comprehensive soil and vegetation survey which has become the model for this type of resource inventory. For areas where the soil and vegetation survey has been completed excellent soil maps and descriptions are available.

Climate

The Mediterranean climate of California as previously noted is characterized by having a definite wet season during the winter and a prolonged summer drought.

The coastal area is marked by moderate temperatures, with small daily and annual ranges, and freezing weather is infrequent. In the Coast Range Mountain districts, temperature is largely controlled by altitude and local topography and is much more equable on the western than on the eastern slopes. In the coastal valleys the summer days are frequently hot, but the nights are cool.

In the Great Interior Valley the summers are hot and dry with temperatures increasing from north to south in the San Joaquin Valley and from south to north in the Sacramento Valley, as the marine air entering these valleys from San Francisco Bay is gradually warmed. The winters are mild throughout the area as is evidenced by the growing of citrus fruits northward nearly to latitude 40° (Anon. 1941).

A very important characteristic of the climate of the California grasslands is the irregular recurrence of floods and droughts. Both features have had a tremendous influence on the development of the California livestock industry. Since the earliest Spanish mission days these events have been occurring and changing the course of the livestock industry. Before the advent of modern flood control structures, floods turned the grasslands of the Sacramento and San Joaquin Valley into great lakes. As we will discuss later droughts have occurred that conditioned vegetational changes besides forcing California livestock industry to move cattle to other areas. The Artemisia/bunchgrass ranges of the Intermountain area of the western United States were largely stocked with Spanish longhorns that were driven from California to escape severe droughts (Young 1981).

Annually the summer drought is broken by the first rain in the fall that conditions germination of the grasses and other annual species. The date of this initial rain is extremely important. If the rain occurs early in October and is followed by subsequent moisture events, temperatures will be high enough to permit forage growth before the advent of winter cooling. if the initial precipitation occurs after November 1st there is little opportunity for fall growth and forage will remain scarce during the winter. Data from the three major range experiment stations in California illustrates this point. At Hopland Field Station in the North Coast Range, October precipitation averages over 5 cm with variability among years resulting in rainfall of less than 1.3 cm only occasionally. At the San Joaquin Experimental Range, rainfall in October averaged 2.4 cm with rainfall being below the 1.3 cm, the effective amount necessary to initiate growth of plants (Murphy 1970) 44% of the time. The Sierra Field Station is intermediate between the two extremes. On the north coast you are sure of winter forage and in the south San Joaquin there is an element of risk.

Pristine Vegetation

As mentioned in the introduction the grasslands of California have changed more under the influence of European man than any other western range type. After 25 years of studying the grasslands of California, Heady (1977) concluded that plant succession tended toward perennial bunchgrass dominants on nearly all well-drained upland sites and that the numerous annuals present dominate low and intermediate successional stages. He also concluded that the annuals prevent many perennial grasses from attaining their dominance and that annuals are now a large part of the climax vegetation on many, if not all sites. The alien species are now permanent members of the grassland and their elimination from the California grasslands is inconceivable.

Stipa pulchra, beyond all doubt, dominated the valley grasslands (Heady 1977). In the southern parts of the grasslands Stipa cernua increases in importance. Stebbins and Major (1965) claimed from genetic and paleobotanical evidence that many endemic species of the California prairie originated from northern ancestors. The original California grasslands apparently are related to the palouse prairie northwest (Daubenmire 1970). Species such as Festuca idahoensis, Koeleria cristata, Poa scabrella and Sitanion Hystrix occupy dominant positions in both grasslands. These species lose their importance from north to south and from the coast inland. Burcham (1957) and Munz and Keck (1959) believed the north coastal prairie had northern relationships while the valley grasslands had more southern affinities.

Quantitative descriptions based on plot sampling of the relict perennial grasslands have not been published (Heady 1977). Originally the valley grassland probably appeared as a bunchgrass prairie, similar to the Palouse prairie, with the exception that native annuals filled the interspaces between the large bunches of Stipa. White (1966) mentions 68 of these subdominant species in Stipa stands with 11% basal cover on Hastings Reservation. Of the 68 annuals, 71% were native species. On shallow soils, a thin or scattered perennial grass stand permits numerous annuals to increase in abundance. Native annuals may completely dominate small areas around vernal pools on hog wallow soils (Lin 1970, Luckenback 1973).

Invasion by Alien Plants

The California environment has been exceptionally subject to invasion by alien plants. Robbins (1940) reported 526 alien spcies of plant growing in California.

Apparently replacement of native vegetation by introduced plants began about the time the first Spanish settlers arrived. Studies of plant remains in adobe bricks used in construction of the oldest portions of the earliest missions indicate introduced species such as the annuals Poa annua, Hordeum leporinum and Lolium multiflorum became abundant concurrently with the advent of settlers while Erodium cicutarium, Rumex crispus and Sonchus asper may have preceeded Europeans (Hendry 1931).

Certain introduced annuals achieved virtual dominance of rangelands at various times. *Avena fatua* and *A. barbata* first became generally widespread (Burcham 1956). As early as 1833 wild oats was an important element in the plant cover of large areas including portions of the San Joaquin Valley (Leonard 1934). *Brassica nigra* was an important dominant at this same time period.

About 1860 the *Avena* species declined in importance and *Erodium* spp increased in dominance in association with *Bromus* spp, *Hordeum* spp and the weedy native *Gastridium ventricosum* (Burcham 1956).

The third wave of invasion was marked by species of comparatively little value for grazing such as *Bromus rubens* and the broadleaf weeds *Hemizonia* spp and *Eremocarpus setigerus* (Burcham 1956).

A fourth wave of aliens included such noxious species as *Aegilops triuncialis*, *Brachypodium distachyon*, *Chondrilla juncea* and *Taeniatherum asperum*. There is no reason to think invasion has stopped. The noxious thistle *Carduus pycnocephalus* and *C. tenuiflorus* have spread and become serious weeds in the California grasslands during the last decade. Exceptional weedy species in other Mediterranean environments such as *Cryptostemma calendula* have not yet been introduced to California (Heady 1977).

No single factor caused the demise of the pristine perennial grassland. In contrast to the *Artemisia*/grasslands of the Great Basin, the California grasslands were subject to grazing by relatively large numbers of pronghorns (*Antilocapra americana*) and tule elk (*Ceruus elophus nannodes*) before the advent of domestic livestock. These native herbivores used the grasslands seasonally during the winter-spring green feed period and it is doubtful that their population densities were sufficient to put severe grazing pressure on anything more than limited areas.

The introduction of domestic livestock was accompanied by the buildup of large feral populations of horses and cattle (Ramirez 1979). Besides ranching operations these feral animals contributed to excessive grazing of the range resource.

Cattle populations peaked in the early 1860's (Burcham 1956). The great flood of 1862 drowned thousands of animals and turned the central valleys into lakes (Kahrl 1978). The next two seasons were extremely dry with large expanses of range virtually devoid of plant cover (Burcham 1956). The severe drought of the 1860's contributed to the end of open range livestock operations and probably hastened the end of the perennial grasses.

During the 1880's California became the leading wheat producing state in the nation with huge areas of former grassland plowed for dryland grain production. Some of this acreage is now irrigated, a portion is still dryland farmed and many of the more marginal areas were returned to annual grasslands.

Exclusion of grazing animals does not mean the return of perennial grasses. Exclusion of grazing animals from an area at the San Joaquin range for 40 years resulted only in the return of a few plants of _Poa scabrella_. The California grasslands are now an annual grassland with a matrix of _Bromus mollis_ and a host of other native and alien annuals.

The Annual Grassland

The annual grasslands have essentially preempted the environment of the pristine California grasslands. Annual grasslands exist below 1200 m in elevation west of the Sierra Nevada Mountains. They are best developed as a treeless ring that borders the cultivated Central Valley. They provide an understory for a _Quercus douglasii_ savanna and in the _Quercus_ woodland (Heady 1977). Removal of the woodland and much of the chaparral results in a new or thickened stand of herbaceous annuals until the woody plants return.

The California annual grassland includes a wide mixture of species, growing on many different habitats and divided into subtypes, depending on the purpose of the investigation (Heady 1977). Janes (1969) selected 20 sites at about 80 km intervals along a transect from the south San Joaquin Valley to southern Humboldt County. The gradient of precipitation along this transect ranged form 13 to 203 cm. In terms of foliage cover, Bromus mollis, B. rigidus and Erodium botrys, in that order, were the principal species occurring with more than 20 cm of rainfall. B. rigidus reached highest proportions near 50 cm of rainfall. On 8 of the 20 sites B. mollis dominated the vegetation. B. rubens and Erodium cicutarium dominated on sites with less than 19 cm of rainfall and were found in measurable quantities to approximately 30 cm. Avena fatua occurred at midrange, 20-63 cm and A. barbata peaked at 87 to 100 cm. In total, Janes encountered 124 plant species.

Phenological changes in the annual grasslands with this mass of species are truly astounding. During the spring the aspect of entire landscape changes depending on which species are flowering.

Productivity

In a unique study located in the annual grasslands near Berkeley, California, Ratliff and Heady (1962) determined that several species reached their individual maximum biomass of the following dates in 1960: Bromus mollis on April 23, Erodium cicutarium on April 30, Medicago hispida on May 8, Bromus rigidus on May 21, Avena fatua on May 21, and Lolium multiflorum on May 28. The biomass for the whole community peaked on May 21. A 19-year study located at the Hopland Field Station showed that the March 1 biomass averaged 90 g per m^2 and the June 1 biomass 309 g per m^2 (see Pitt 1975). Year-to-year variation halved and doubled these averages.

The weight of herbage biomass at the end of the growing season differs several fold among years. Duncan and Reppert (1960) reported a production range of 775 to 2900 kg per ha over a 25-year period on the San Joaquin Range. Above ground standing herbage on March 1 varied between 24 and 218 g per m^2.

There have been several attempts to correlate biomass production with temperature and precipitation (Murphy 1970, Pitt 1975, Duncan and Woodmansee 1975). Murphy found November precipitation correlated with forage production several months later. Pitt included temperature and periods without moisture events in his equations. Generally if germination occurs early enough in the fall, production will be high but periodic spring precipitation without dry soil between showers until May is also needed for greatest biomass yield (Hooper and Heady 1970).

Range Condition Standards

Throughout the western range, departure from climax has become established as a standard by which to judge range condition. On the California annual grasslands this approach is not valid because return to the pristine vegetation is impossible. Sampson et al (1951) described successional trends in the annual grasslands due to differences in grazing pressure. Under reasonable grazing management, tall species such as *Avena fatua* and *Bromus mollis* dominate, but with heavy grazing shorter species prevail. Close grazing delays fall growth and reduces winter growth (Talbot and Biswell 1942, Bentley and Talbot 1948, Hedrick 1948, Hervey 1949). Heady and his students have shown that the amount of litter and mulch left on the range is the key to maintaining range condition (Heady 1956). Approximately

500 kg per ha of above ground plant residue at the beginning of the rainy season indicates proper intensity of grazing use (Heady 1965). This standard applies at 75 to 100 cm of rainfall.

Range Improvement Technology

After World War II considerable effort was devoted in California in finding a perennial grass species suitable for revegetation of the annual grasslands. This search proceeded in two directions: first to develop a cultivar of *Stipa pulchra* with the seed production, germination and seedling vigor to permit its use as a range vegetation species, and secondly, to screen exotic species of perennial grasses for this use (Love 1951). The exotic species evaluated included summer dormant selections of orchard grass (*Dactylis glomerata*) smilo (*Oryzopsis miliacea*), and hardinggrass (*Phalaris tuberosa*) (Love 1952).

Of the grass species tested hardinggrass proved most successful and was widely planted on the annual ranges, especially in higher potential sites (Love et al 1953). Generally two major problems have limited the success of hardinggrass on the annual range. Seedling vigor is rather poor and subsequently seedling establishment is very difficult. Perlagrass, (*P. tuberosa* var. *hirtiglumis*), has better seedling vigor and with proper weed control can be established much easier (Kay and Owens 1970). Both perlagrass and hardinggrass have proven adapted only to the higher potential sites on most rangeland sites. They will persist in swales and on moist north facing slopes, but not in competition with annual grasses on other sites.

Range Legumes

As a byproduct of the search for a perennial grass species for the annual grasslands another source of plant material, annual legumes, was discovered and developed. In 1944 the Division of Agronomy of the University of California at Davis received a small amount of seed of annual legumes from the U.S. Dept. of Agric. Among these packets was a sample of rose clover (Trifolium hirtum) that had been collected in Turkey (Love and Sumner 1952).

The California ranges had always contained a variety of native annual legumes species belonging to several genera. The exotic legume, bur clover (Medicago polymorpha), had long been a part of the annual ranges to the point that it was considered native by ranchers. Bur clover can be especially abundant in certain years on the more basic soils.

Rose clover and, especially in northwestern California, subclover (Trifolium subterraneum) have proven to be highly adapted to many rangeland sites.

The addition of the annual legumes to the rangeland community accomplishes two things. First, it greatly increases the quality of forage produced on the ranges by increasing protein content. Secondly, the legumes add nitrogen to the rangeland ecosystem enhancing the subsequent growth of grasses and, therefore, total productivity.

To properly culture the annual legumes it is necessary to take steps to assure that the legume seeds are inculcated with Rhizobium (Holland and Street 1965) and to provide the proper nutrient status. Generally fertilization with 560 kg/ha of single superphosphate is required to assure adequate establishment of the legumes (Murphy et al 1973). Grazing is essential to stand maintenance. Because of the nitrogen furnished via legumes, the grasses become exceedingly competitive and will crowd out the legumes if not removed each y

A number of cultivars of subclover and other exotic legume species is available from Australia. California currently imports virtually all of its annual legume seed from Australia and takes advantage of the Australian plantbreeding program for new cultivars. Rose clover is grown in Australia almost exclusively for seed production for the California market.

Weed Control and Revegetation

Because of the constant difficulty in trying to establish perennial grass and legume seedlings, weed control systems were developed to reduce competition. The most highly developed system involved the use of the herbicide paraquat (1,1'-dimethyl-4,4'-bipyridinium) (Kay and Owen 1970). After the first fall rain initiates germination, bands of paraquat are sprayed on the annual vegetation. Paraquat is a contact herbicide which is deactivated as soon as it touches the soil surface. Seeds of annual legumes or perlagrass are drilled in the bands of dead vegetation. Single super phosphate is banded over the legume seeds. The advanced technology system has never gained wide acceptance on the California annual range. There are probably several reasons for this lack of acceptance. The California annual ranges are sufficiently productive on normal years that ranchers do not have an overpowering necessity to improve the ranges. A sufficient extension and educational program has not been mounted to explain and sell the advantages of the paraquat weed control-revegetation system. The classification of paraquat as a restricted pesticide has not helped the acceptance of the system.

Microenvironment of a Dynamic Annual Community in Relation to Range Improvement

Detailed microenvironmental monitoring of annual rangeland communities in conjunction with weed control and revegetation with the paraquat system have yielded valuable insight on the dynamics of these communities (Evans et al 1975).

When seasonal trends in light intensity are superimposed on trends of temperature and moisture, especially these altered by plant growth, limiting factors affecting plant growth throughout the period form a comprehensive mosaic.

Available soil moisture permitted seed germination, emergence and plant growth. Temperature controlled the general rate of plant growth. Both low temperatures to inhibit seed germination and high temperatures to accelerate seedling growth influenced establishment. An inverse relation between favorable temperature and available moisture, as is typical for a Mediterranean climate was shown.

Light was the overriding competitive factor in preventing the establishment of annual legume or perlagrass seedlings. Shading from the more rapidly growing annual grasses had deleterious effect on establishment of replacement species. Rose clover was more tolerant to shading than subclover and both species were much more tolerant than perlagrass.

Wildlife Relations

The tule elk were found only in the Central Valleys of California where they inhabited the once extensive marshes and the pristine grasslands. Their disappearance was primarily due to loss of habitat. This habitat has become some of the most productive intensive agricultural land in the United States and there is little chance of increasing the herds of this species. Tule elk were introduced into Owens Valley (Inyo County), Cache Creek (Colusa County) and a state park at Tupman, near Bakersfield, California. At this time, these are the only areas where the tule elk are found (Nelson and Hooper 1976).

There is also little opportunity to return the pronghorn to the Central Valley because of loss of habitat. Elsewhere in California the pronghorn populations have doubled in the past 10 years in a very successful management program.

Apparently there are few free roaming horses on the California annual grasslands. There have been reports of a few feral horses in San Luis Obispo and Tehama Counties on private rangelands. During Spanish mission times there were large herds of feral horses on the California grasslands.

There are about 12,000 feral pigs in California, many of them located on the north coast, in the central valleys and on the channel islands. These pigs are both the European wild pig and domestic pigs gone wild (Nelson and Hooper 1976).

Blacktailed deer are the most numerous big game animal on the California grasslands. Although these animals are primarily browsers and need woodlands and brushfields for cover, deer do feed and spend time in the grasslands.

The annual grasslands provide habitat for a large, diverse population of rodents which have a considerable impact on the vegetation (e.g. see Fitch and Bentley 1949).

The California grasslands are important habitat for valley quail. This is a very important recreational-hunting species with many landowners engaged in selling hunting privileges. Wild turkeys and chukar partridges are locally important.

Off Road Vehicles

The southern California deserts have received most of the attention on the impact of off-road-vehicles (ORV) on public lands. Near each town and city in the California grasslands there is local use of annual grasslands by ORV's. Near Hollister, California the State Parks Systems maintains ORV sites where they attempt to rotate use, revegetate disturbed sites and use sediment traps to keep erosion products on site (Kay 1980). The Bureau of Land Management (BLM) attempted a similar program near Panoche, California in a management area. This program was not acceptable because ORV users did not want to use slopes after they became eroded.

California has three leading scientists in assessing the effects of ORV's on the environment; Howard Wilshire, U.S. Geologic Survey, Menlo Park; Robert Webb, Stanford University; and B.L. Kay, University of California, Davis.

Predation

As with most range types in the west the livestock using the California annual grasslands have considerable problems with predation. The major predator is the coyote. Sheep are a major livestock industry and are especially important in northwestern California. Most sheep operations are farm flocks in fenced pastures and are not herded.

The Predator Control Division of the Fish and Wildlife Service, U.S. Dept. of Interior has about 100 biologists engaged in predator suppression in California. The Fish and Wildlife Service estimates annual predator losses in California at $20 million in terms of consumer cost (Thompson 1980). Obviously not all of this loss is on the annual range. If the control program was stopped losses are estimated at $100 million. Besides the cattle and sheep industry, California turkey growers suffer considerable damage from coyotes. Many livestock operations suffer predation from free roaming dogs.

Livestock Management

The California annual ranges are unique in the west in that their green feed period occurs when most other range livestock operations are feeding conserved forages such as hay. The annual ranges provide a winter environment for cattle and sheep that use other types such as sagebrush/grass or timbered ranges during the summer. Many annual range operations have grazing permits on National Forest during the summer. Cattle are shipped from the annual ranges to western Nevada and southern Oregon for the summer besides to the mountains of California. Anything that influences the livestock operations on the annual ranges influences range utilization on a much larger area. Changes in conservation policy on U.S. Forest Service or National Resource land in terms of the number of animals permitted to graze, season of use or grazing fees has an impact on the annual range.

Scientific Data Base

California is blessed with one of the world's greatest University systems and an associated Agricultural Experiment Station with a long history of involvement with the range livestock industry. Three major range livestock experiment stations have had a strong influence on range research. The Hopland Field Station has an excellent staff and a long record of valuable research contributions. The Sierra Foothill Range Field Station does not have the long record of research for a data base that exist at Hopland because it is relatively new, but it has excellent facilities. Unfortunately the San Joaquin Experimental Range has recently been closed by the Pacific Southwest Forest and Range Experiment Station of the U.S. Forest Service. After a long history of involvement in research on the annual grasslands the Forest

Service has ceased to have a viable research program on annual grasslands.

The University of California has been fortunate to have on its staff Drs. A.W. Sampson, the father of range science; H.H. Biswell, ecologist and leading proponent of prescribed burning; R.M. Love, the agronomist who had much to do with the introduction of annual legumes; and H.F. Heady, the distinguished annual grassland ecologist and internationally recognized range scientist. The question now is who are the young range scientists of sufficient stature to carry on the work of these brilliant scientists?

Several State Universities, including Chico, Humboldt, Fresno, and California Polytechnic, offer natural resource degrees including range science.

The California Agricultural Extension Service is one of the largest and most well-known in the United States and has a long history of being involved in range projects.

Integrated Pest Management

A major problem in the management of annual rangelands is the development of integrated pest management programs, especially concerning weed control and range improvement. Species such as the noxious thistle Silybum Marianum find habitat in areas disturbed by rodents and the rodents expand their population based on the increased production of large achenes by the thistle (Young et al 1978). Biological control agents are available for the thistle in the form of a seed eating insect. Introduction of the biological control agent may reduce the rodent's supply of seed that would limit predation, but not necessarily result in a net decrease in viable thistle seeds. Such complex ecological problems need to be approached on an integrated pest management basis.

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